Fire Fighting in Aerospace Product Development:

A Study of Project Capacity and Resource Planning in an Aerospace Enterprise

by

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Abstract

It is broadly recognized in the aerospace industry, as well as many others, that organizations which effectively execute development projects to meet desired cost, schedule, and performance targets for their customers produce higher levels of customer satisfaction and also a significant source of competitive advantage. Continually meeting the needs of the customer through effective project execution allows a company to become a preferred supplier favored in source selection for follow-on contracts and new development projects necessary for business growth.

This research effort examines one aerospace company, which has multiple, diverse development projects on-going at any one time across several business units. The motivation for this thesis is to explore the product/system development capacity of the enterprise by analyzing the historical program performance of major projects, understanding the level of problem projects or fire fighting within the project pipeline, and the perceived causes of poor project performance.

In addition, system dynamics models are developed to analyze the dynamics associated with project planning and resource planning strategies for both multi-project and single project scenarios. This analysis provides insight into the potential for project pipeline "tipping" and the effects of various project management and resource planning strategies in an aerospace product/system development context. Such analysis is believed to provide greater insight and opportunity to improve the product/system development performance for the enterprise.

Thesis Supervisor: Professor Nelson Repenning

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Chapter 1

Introduction

1.1 Motivation

It is broadly recognized in the aerospace industry, as well as many others, that organizations which effectively execute development projects to meet desired cost, schedule, and performance targets for their customers produce higher levels of customer satisfaction and also a significant source of competitive advantage. Continually meeting the needs of the customer through effective project execution allows a company to become a preferred supplier favored in source selection for follow-on contracts and new development projects necessary for business growth.

Meeting such a goal can be challenging in the aerospace industry, which serves the US Department of Defense (DoD) as its principal customer and market. Since the end of the Cold War in the late 1980s, product and system needs from the DoD and associated end-users continue to increase in terms of technology, functionality, and complexity. Meanwhile, DoD budgets have been reduced significantly resulting in competitors vying for limited development and acquisition funds. The result being that most, if not all, development projects sponsored by the DoD are highly competitive and include ever increasing levels of technical complexity and performance challenges under constrained cost and schedule objectives. As such, project execution risks can be high and many projects suffer from substantial cost and schedule overruns and even project cancellation due to poor project performance. Therefore, organizations, which have the capability to manage and execute such complex projects successfully, are highly desired and have a distinct competitive advantage in the market place.

This research effort examines one aerospace company, which has multiple development projects on-going at any one time across multiple business units. The projects include basic R&D, advanced development, full-scale engineering and manufacturing development, and upgrades to a broad range of products and highly complex systems. A principal challenge in executing such a diverse project base is the development of robust project plans as well as timely and appropriate allocation of product development personnel.

While the organization analyzed has made substantial gains over the last decade in project performance on major, high-value projects by improving development process, management policies, bolstering critical skills, and resource planning systems, a number of projects continue to suffer from poor project performance or fire fighting. As such, several strategically important projects have not achieved their planned follow-on business success, that is – "going into production". In this research, I hope to develop insight into the causes behind poor project performance and fire fighting to understand the critical factors in improving the organizations capacity to execute development projects successfully.

In addition, development capacity analysis has not been performed by the target organization to date as their business capacity is often viewed as market limited rather than resource limited. I explore the product/system development capacity of the enterprise and analyze relationships to aggregate resource planning methodologies and policies. My analysis seeks to provide insight and opportunity to improve product development performance.

1.2 Business Context-Aerospace

The aerospace business is driven by system, product, and service needs for national security of U.S. and allied defense organizations. Most of the products/systems developed are a result of direct procurement actions by the U.S. DoD, where request for proposals (RFP's) solicit aerospace contractors for technical, cost, and schedule proposals for products and/or services defined by a statement of work (SOW). In turn, aerospace contractors compete to win these contracts. These projects are either fixed-price[1] or cost-plus[2] contracts, usually awarded to a single contractor. Fixed price contracts are typically employed on projects for the production of already developed products or systems while cost-plus contracts are typically employed on higher risk, product development projects.

While aerospace companies invest in technology R&D, its project pipeline is largely determined by DoD sponsored contracts. Unlike a commercial business, where projects are internally funded, an aerospace company depends on its ability to win new development projects and follow-on production projects from the DoD. Furthermore, these contracts must often meet pre-defined technical performance, cost, and schedule constraints of the DoD customer.

1.3 Research Outline

The research begins with a review of the project performance history of major and strategic programs within the enterprise from December 1994 through September 2002. A brief review of the project metrics is presented, followed by a detailed review of the aggregate project performance metrics. The research will summarize the level of troubled projects across the enterprise over this time period. In addition, the impacts of poor project performance will be evaluated by considering the cost of poor quality (CoPQ) as it is measured by the aerospace organization.

1 Fixed price projects are those whose contracts which are negotiated for products and services to be provided at a fixed cost to the government. Any project cost overruns are to be paid for by the aerospace contractor.

2 Cost-plus projects are those contracts, which are negotiated for products and services to be provided at a target cost used to obligate funds and establish a cost ceiling. Any project cost overrun is to be paid for by the government customer and must be first approved by the government if the contractor is to be reimbursed.

The level of troubled projects is considered an indicator of the organization's capacity to execute projects to their intended cost, schedule, and performance targets. Given the historical project performance, the project portfolio is analyzed to determine if there is empirical evidence of a particular mix, type, and/or quantity of projects, which had caused the organization to exceed its project execution capacity. The analysis is performed across five core business areas of the aerospace enterprise as well as a specific business area within the organization for which considerable data and personnel were available for consultation. The portfolio or project pipeline for this specific business area is examined using both the enterprise categorization of projects as well as a project categorization more commonly referred to in product development literature.

The primary causes of poor project performance or fire fighting are then examined. Corporate surveys and assessments are investigated and six central causes of project fire fighting are identified and described. In addition, I consider several questions that help characterize the nature of project fire fighting: "When does fire fighting typically begin?", "How long does fire fighting last?", and "How are fires put out?".

Given the identified causes of project fire fighting, the topics of resource planning and allocation are examined as these are core elements associated with three of the primary causes identified by the organization: poor bid and proposals for projects, poor project planning and execution, and staffing issues. Here, several interviews with company mid-level and senior-level managers were completed to develop perspective on the issues surrounding resource planning and allocation behavior and policies. In addition, a limited survey of the existence of staffing queues is presented. Here, I explore the organization's performance in staffing new project starts on-time and to specific project plans. The premise is that staffing queues are an indicator of project overload within the organization.

The research then focuses more deeply on the topic of project execution capacity and overloading. A brief review of published research helps define the meaning of project capacity and identifies commonly recognized indicators of project overload and fire fighting in product development. Given these indicators as well as the business context and feedback from company management, an aerospace business causal loop is developed which describes the motivation and behavior associated with generating conditions for sustained fire fighting within the project pipeline. The causal loop supports the hypothesis that, in an aerospace context, firefighting or overload is not necessarily driven by the number of on-going projects but rather how well the project plans match both the resources needed and the resources available to execute the project pipeline successfully.

Next, two system dynamics models are presented: a multi-project model and a single project model. These models investigate the conditions, which can induce project pipeline "tipping" as well as the importance of allocating the right resources to projects. These analyses provide insight into the dynamics of the project pipeline and introduce alternative management policies, which improve decision-making when dealing with troubled projects in addition to improving overall project execution.

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Chapter 2

Project Performance Research

2.1 Red-Yellow-Green Metrics

To understand the organization's capacity to execute projects successfully, the first step was to review performance history for major and strategic projects across the enterprise. Project performance for these projects was compiled for the time period from December 1994 to September 2002 and is shown in Figure 1.

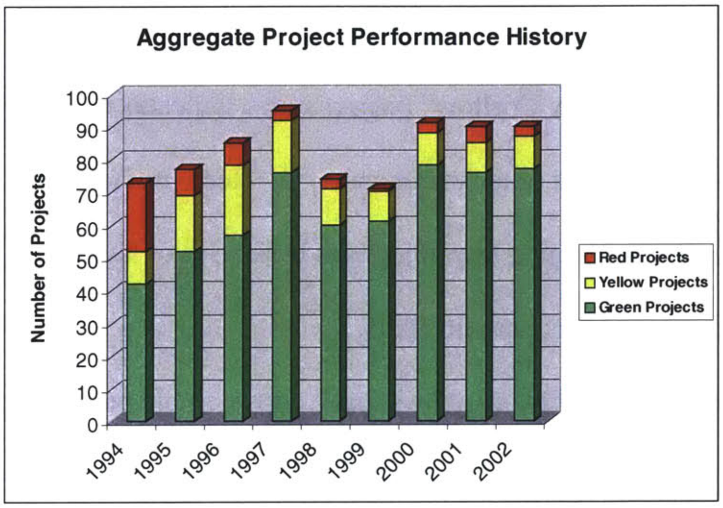


Figure 1. Aggregate Project Performance History – "RYG" Status for Major and Strategic Projects (12/94 through 9/02)

"Red-Yellow-Green" metrics are used to assess and track the status of major and strategically important projects and are based on cost, schedule, technical, and customer satisfaction measures. Cost and schedule are objective measures based on the DoD's standard earned value method[3,4] (EVM) for measuring project performance while technical and customer

[3] Q. Flemming and J. Koppelman, "Earned Value: Project Management", Project Management Institute – September 2000

[4] David Galley, "Earned Value Management: project management with the lights on", January 15, 2002,", www.bcs.org.uk/branches/kingston/projman.ppt

satisfaction measures can be more subjective and are often based on the project team's estimate and perspective. A summary of the metric criteria is shown in Table 1.

Table 1. "Red-Yellow-Green" Metric Criteria

Project Performance	Green	Yellow	Red
Cost	CPI $\geq$ 0.95	0.90 $\leq$ CPI < 0.95	CPI < 0.90
Schedule	SPI $\geq$ 0.95	0.90 $\leq$ SPI < 0.95	SPI < 0.90
Technical	No Issues	Minor Issues	Major Issues
Customer Satisfaction	Good	Marginal	Poor

In general, a "Green" project status indicates that the project is on-track to meet key objectives and customer needs. A "Yellow" project status indicates that the project is having difficulty in certain programmatic or technical areas. A "Red" project status indicates that the project has substantial issues meeting key objectives indicative of significant cost and schedule overruns and/or technical performance shortfalls.

The project performance history shows that a considerable percentage of the important projects were either "Red" or "Yellow" in the mid to late 1990s. Perhaps more important is the fact that despite decisions to exit specific business segments, focus on core competencies, and to continue development process improvements, there continues to a sizeable percentage of projects which are in trouble, approximately 15% on average for the last four years, thus indicating a continuous level of fire fighting across the enterprise. The percentage of programs, which were "Red" or "Yellow" over time, is summarized in Figure 2.

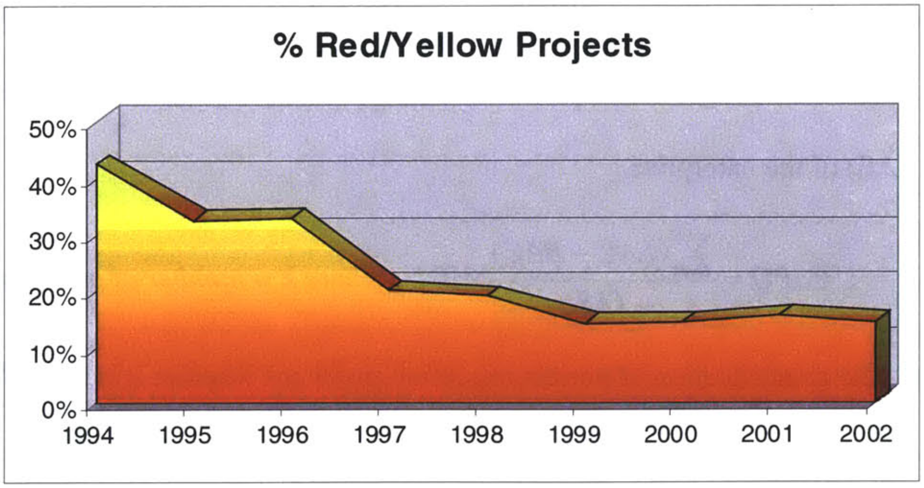


Figure 2. Percentage of Strategic/Important Projects in Trouble

Based on discussions with company management, the drop in the amount of troubled programs from 1994 to 1997 is attributed to the maturation and completion of troubled projects and the reduction in the number of lines of business from eight to five. The three lines of business or business areas, which were exited, suffered considerable project execution issues and represented a more than one-half of the troubled projects across the enterprise over that period of time. Currently, there are seven active business areas, two of which were added in the year 2000 as a result of a corporate restructure. These two additional business areas are geographically separate from the five heritage business areas. The five heritage business areas are geographically co-located and often share personnel resources.

2.2 Cost of Poor Quality

Of course, troubled projects by definition impact cost. Here, the CoPQ is examined to understand the impacts associated with the organization's project execution issues. While CoPQ has many definitions[5,6], CoPQ is defined here as a percentage of total annual sales and is

[5] Jack Campanella, "Principles of Quality Costs: Principles, Implementation and Use", American Society for Quality, 1999.

[6] "Cost of Poor Quality-COPQ", http://www.isixsigma.com/dictionary/Cost_of_Poor_Quality_-_COPQ-63.htm, March 2003

computed as the difference between the cumulative approved budget at completion (BAC) and the cumulative estimated budget at completion (EAC) for all active projects divided by the total annual sales (TAS) of the enterprise.

$$CoPQ = \frac{\sum_{1}^{k}(EAC - BAC)}{TAS} \times 100 \text{ , } \textit{Where } k = \textit{number of projects}$$

CoPQ is the quantification of project execution problems whether it is caused by poor project cost estimation, unanticipated rework/scrap, supplier issues, schedule delays, or any other issue that results in cost growth for a project.

The CoPQ for the organization is shown in Figure 3 and is plotted over the period from 1998 to 2002. The figure shows that the impact of poor quality, i.e., project execution issues exceeded 10% of annual sales for three of the last five years. In the previous two years, the CoPQ has reduced considerably. While the reason for the drop in CoPQ is unknown, some company management personnel have reported that this is due to many large, previously, troubled projects reaching completion thus having more stable cost positions. Therefore, it is unclear if this trend in reducing the CoPQ is related to a specific business action or simply a conditional response to the maturity of projects in the pipeline.

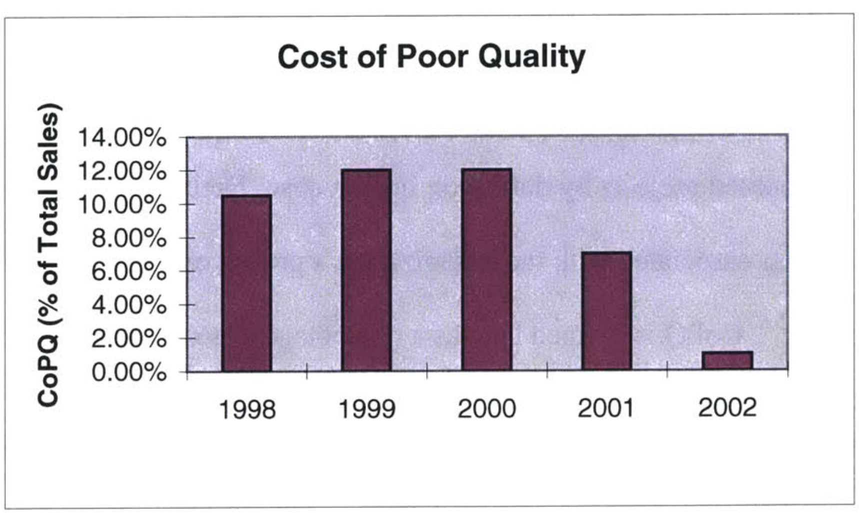


Figure 3. Cost of Poor Quality as a Percentage of Annual Sales

In addition to the budgetary impacts of poor project performance, there are also less quantifiable impacts such lost opportunities for new business due to customer dissatisfaction, delay or loss of production/follow-on funding, loss of business due to competitive/alternative offerings, customer reluctance to fund additional work through the company due to the appearance that the organization has more than it can handle for work, "knock-on" effects to other projects due to the unavailability of resources already committed to fire fighting, diversion of management attention from strategic and business development efforts to fire fighting and status reporting, reduction in employee morale, and the like.

2.3 Portfolio Analysis

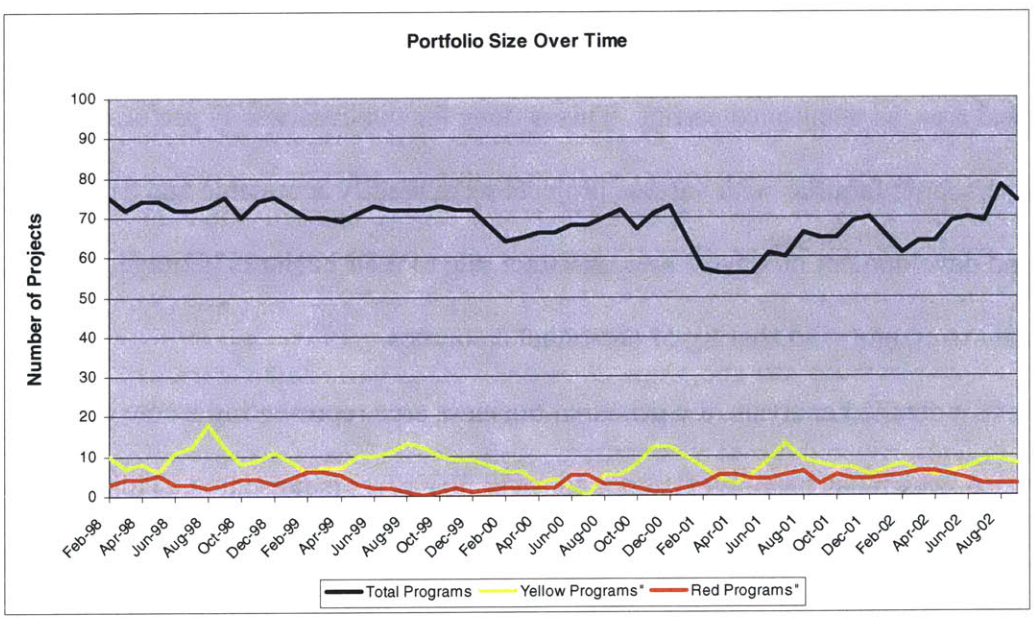
The project portfolio is examined to determine if there are any relationships between the number and/or type of projects in the pipeline and poor project execution and fire fighting, I first examine project performance across the five-core business areas located within the same geographical area, as mentioned earlier. This is done for two reasons: 1) performance data and company personnel familiar with various projects were readily accessible and 2) business policies and development processes are consistent due to their business heritage, collocation, management oversight, and sharing of personnel resources.

Next, a detailed analysis of a principal business area representing a core competency of the enterprise, which has been in existence for over 30+ years is presented. This business area, which is referred to as the MC business area, is of particular interest since it has experienced significant project performance issues on two major development projects that began in the mid 1990s. It is believed that the conditions exhibited here over the last eight years are indicative of negative project dynamics also experienced in other business areas within the enterprise.

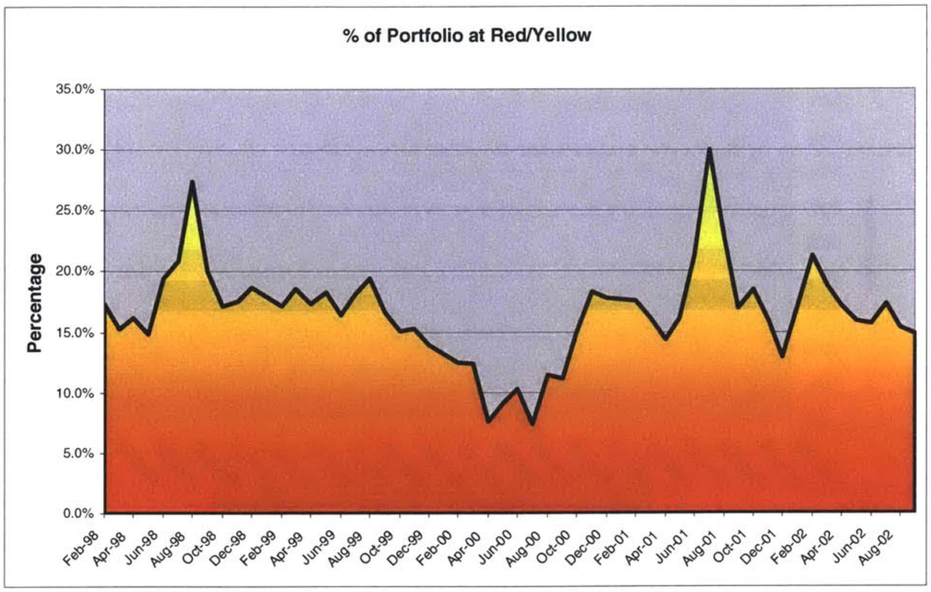
Five Core Business Areas (1998 – 2002)

A detailed portfolio analysis is presented here for the five core business areas of the enterprise. Project performance issues are compared against various project types to determine if there is a particular type of project that is more prone to issues than others. Figure 4 shows a number of graphs which describe: the total number of projects and the number of projects which are "Red" and "Yellow", the percentage of projects that are "Red" or "Yellow", the portfolio mix by project type, and the percentage of projects which are "Red" or "Yellow" by project type.

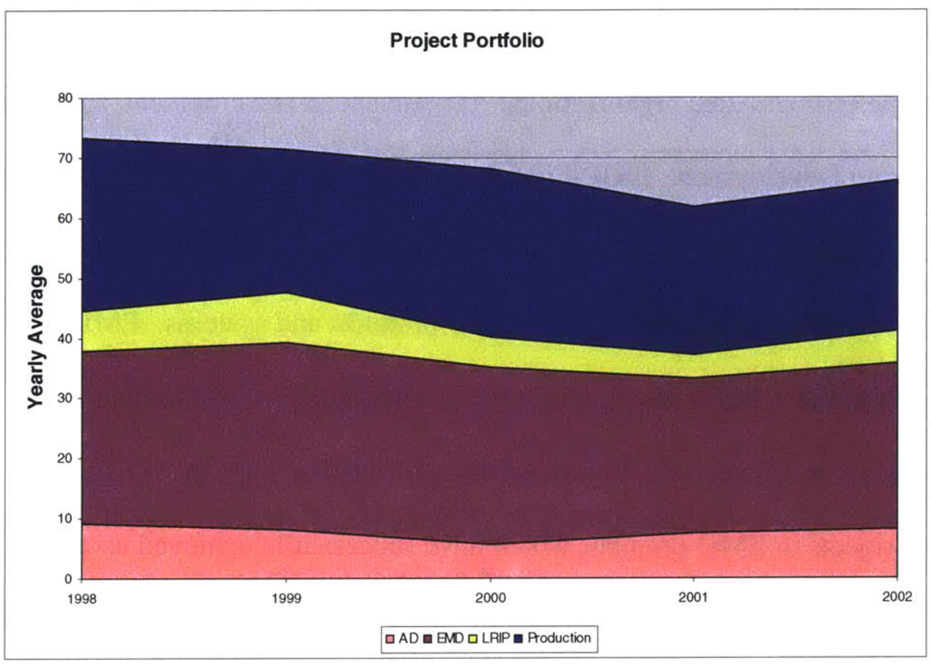
As the graphs illustrate, at any given time there are approximately 69 active projects on average over the time frame analyzed. Of the those active projects, 16.6% of them were in trouble being at either a "Red" or "Yellow" status which is consistent to the aggregate results for the enterprise reported in Figure 4 over this same time period.



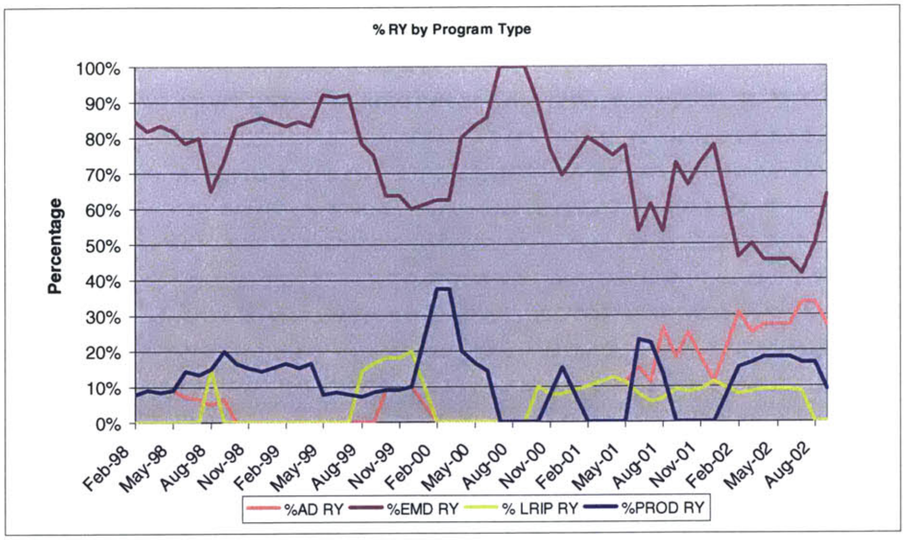
a) Total number of projects and the number of projects which are Red and Yellow



b) Percentage of projects that are "Red" or "Yellow"



c) Project portfolio by project type – AD, EMD, LRIP, and Production



d) Percentage of projects which are "Red" or "Yellow" by project type.

Figure 4. Portfolio Mix and Project Performance for Five Core Business Areas (1998 – 2002)

There are four specific project types, which are evolutionary in nature and formally recognized by the business area organizations: AD-Advanced Development, EMD-Engineering and Manufacturing Development, LRIP-Low-Rate Initial Production, and PROD-Production. AD projects are projects, which involve development, and use of advanced technologies intended to demonstrate feasibility and performance of new products and systems. EMD projects are projects, which involve a full-scale development of a product or system intended for future production often using advanced technologies demonstrated in some AD phase. LRIP projects are follow-on projects to EMD projects, which have successfully achieved acceptance by the customer for military use and acquisition and are being transitioned for full-rate production. Finally, Production projects are projects, which have successfully completed EMD and possibly LRIP phases and involve the manufacture and support of developed systems.

The project mix described in Figure 4c shows that the mix of projects is relatively constant. On average, 11% are AD projects, 41% are EMD projects, 9% are LRIP projects, and 39% are Production projects. Of significance is the fact that a majority of projects, which are

"Red" or "Yellow", are EMD projects. In fact, as illustrated in Figure 5, on average, 74% of the projects that are in trouble are EMD projects thereby being the primary source of fire fighting within the organization. Going further, on average, almost 1 out of every 3 (29%) EMD projects get in trouble, which is in contrast to AD, LRIP, and Production projects, which exhibit a lesser fire-fighting rate of only 15%, 11%, and 5% respectively.

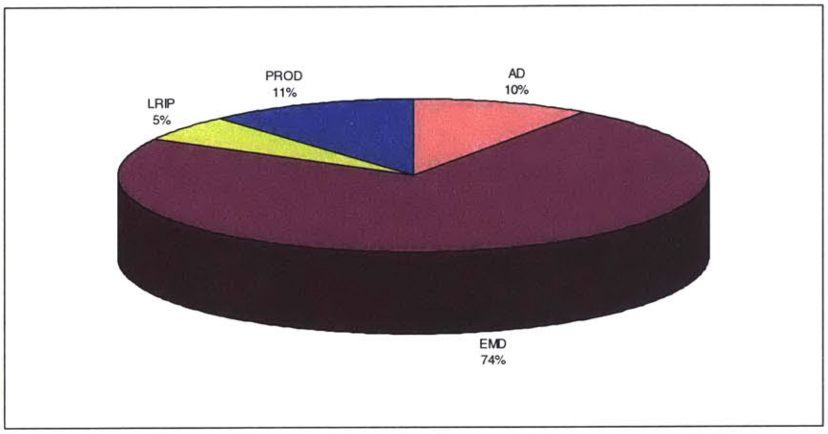


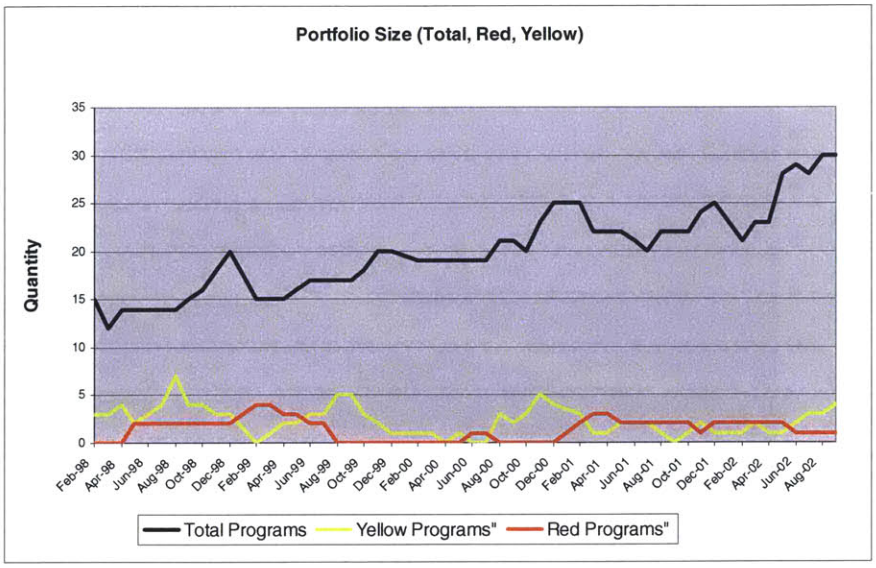
Figure 5. Breakdown of Average Percentage of Red/Yellow Projects by Type

The fact that EMD projects tend to be in trouble more than other project types is not a surprise to the company's management. EMD projects generally have higher levels of development risk and uncertainty than other project types and also require a greater coordination across disciplines within and across engineering and manufacturing boundaries due to the concurrent nature of development. In particular, the combination of demanding cost/schedule constraints, high performance objectives, and advanced technologies often result in projects which are difficult to execute and often place an excessive demand on the organization's best personnel talent and critical skills since there are usually more projects demanding their attention than there are staff with the critical skills and experience needed to support them.

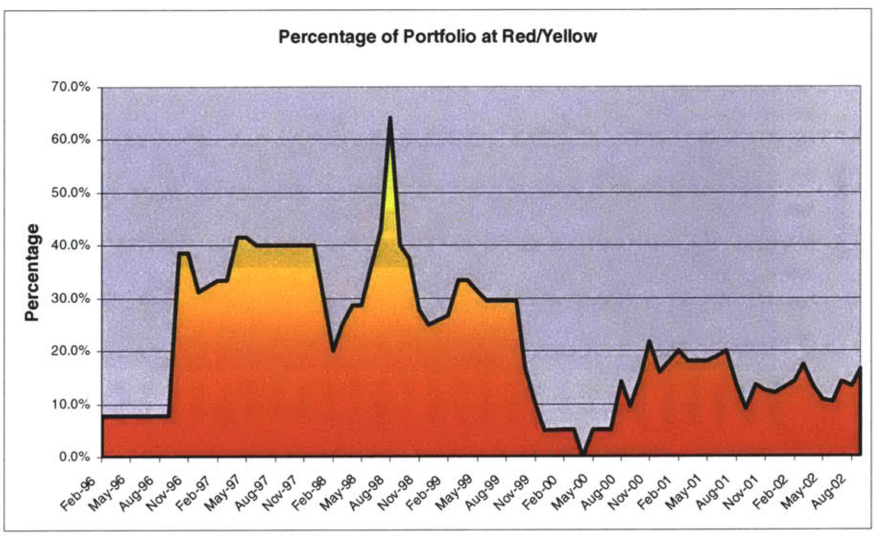
A Detailed Look at the MC Business Area (1996 – 2002)

The MC business area is a core business line that has been operating successfully for many years. Project performance data was collected from the year 2002 back to the beginning of 1996. The MC business area is of interest because of major development contract wins in late 1995, which in hindsight created a considerable demand on the resources within the organization so much so that some managers feel that the organization was well over its capacity to adequately execute them. In particular, two major projects, which started in late 1995, and turned "Red" approximately 12 to 18 months after their start are recognized as being the primary source for fire fighting within the business area from 1996 to 1999. I begin by reviewing the number of projects in the pipeline, project performance, and the portfolio mix to understand the organization's capacity to execute the then current "strategic/important" projects.

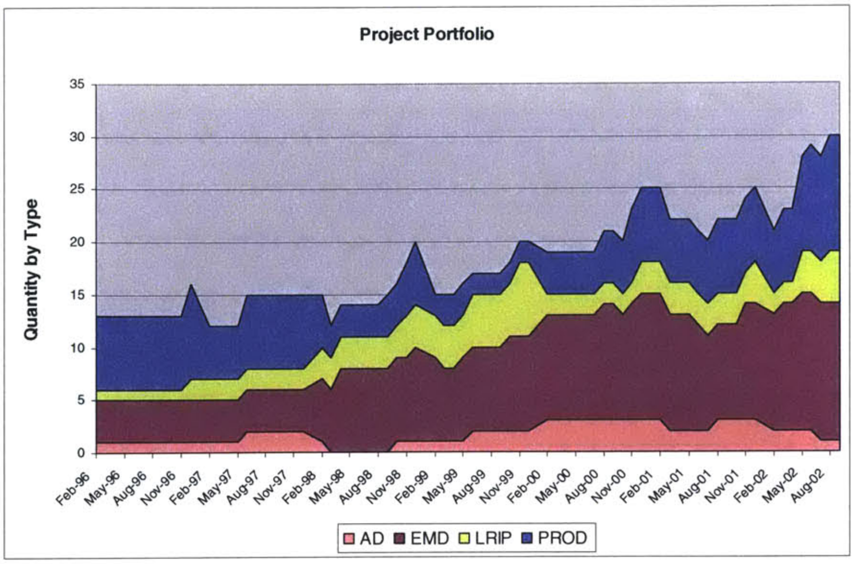
The MC business area has had on average 18 projects on-going at any one time. Of the average total, 2 are AD projects, 8 are EMD projects, 3 are LRIP projects, and 5 are Production projects. In addition, on average, 22% of these projects experience fire fighting, i.e., were "Red" or "Yellow". Of the 22% of troubled projects, 7% are AD projects, 64% are EMD projects, 0% is LRIP projects, and 29% are Production projects. Once again, the majority of projects in a fire-fighting mode are EMD projects. A detailed view of the monthly project portfolio and performance data is shown in Figure 6.



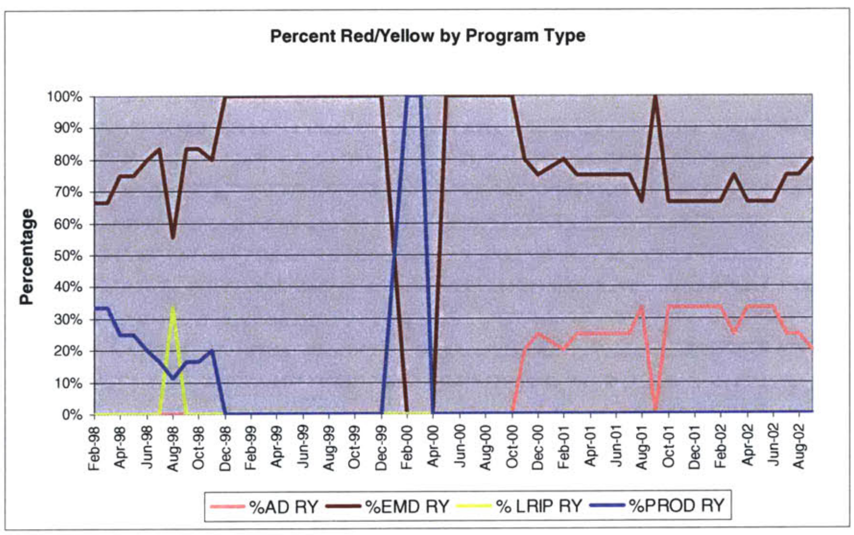
a) Total number of MC projects and the number of projects which are Red and Yellow



b) Percentage of MC projects that are "Red" or "Yellow"



c) MC project portfolio by project type – AD, EMD, LRIP, and Production



d) Percentage of MC projects which are "Red" or "Yellow" by project type.

Figure 6. Portfolio Mix and Project Performance for the MC Business Area (1996 – 2002)

While the mix of projects and the percentage of troubled projects are similar to that of the reported in the aggregate and 5 core business statistics, the time phased profile of the percentage of Red/Yellow projects shown in Figure 6b is particularly interesting. The graph shows that beginning in September/October, 1996 through September/October, 1999 there is a significant increase in the level of troubled programs. Based on discussions with MC business area management, this 3 year time period involved a significant level of fire-fighting across the organization, the majority of which were caused by the 2 major contracts/projects won in late 1995 along with additional contracts/project wins associated with these 2 major projects. This data along with feedback from company personnel suggests that the MC business area was well over its capacity to execute the work scope in the project pipeline. Furthermore, some of the managers interviewed commented that this extended increase in the level of fire-fighting has occurred in the past in other business areas and is usually associated with too much and/or aggressive EMD development work in the pipeline. In fact, there is some evidence that suggests that this phenomenon is periodic and typically associated with aggressive efforts to win new business. These aggressive business development efforts usually translate into aggressive bid positions leading to higher risk and over-constrained (cost, schedule, and technical) projects, which creates a condition where the organization is beyond its capacity to execute the project at the promised cost, schedule, and performance conditions.

I examine this more closely by taking a look at the budget history for the 2 major projects mentioned; they will be referred to as project "A" and project "I". The project budgets are normalized to the original budgeted project cost and then plotted over time in Figure 7.

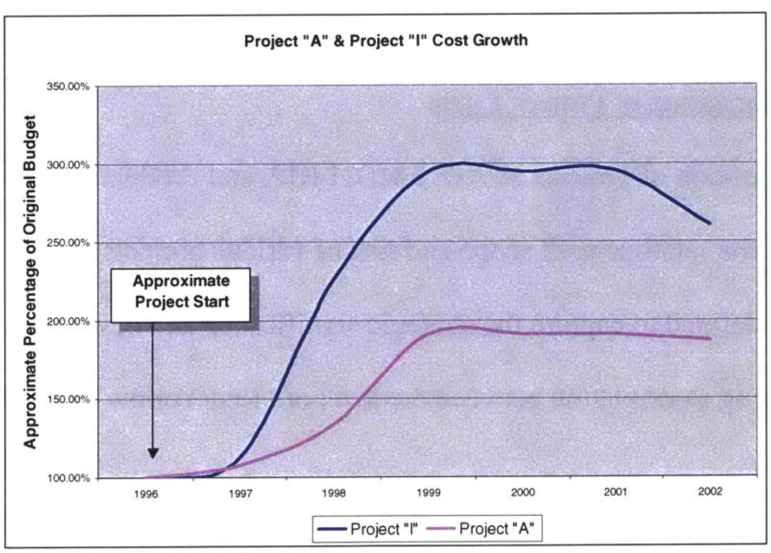


Figure 7. Project "A" & Project "I" Cost Growth

Both project "A" and "I" began in late 1995/early 1996 and were major strategic wins for the business area. These EMD projects were platform projects in that substantial follow-on and derivative project business was expected following successful completion which was originally targeted at approximately 48 months after the project start. Both projects were "Red" approximately 12 to 18 months after the project start and suffered considerable cost growth. While the cost growth was attributed to both customer and company factors, both sides acknowledge that the project was too aggressively planned. As a result of several factors such as process streamlining, limited testing, and too few resources, both projects suffered considerable development defects and rework and the project schedules were extended by about 2 years. The impact of these events created considerable tension within the company for critical skills and personnel for fire fighting. In addition, derivative projects targeting use of project "A" and "I" products also suffered as a result of the schedule, cost, and customer satisfaction impacts.

While the project statistics are interesting, there is no clear correlation between the number of project types and the number of projects that the organization can execute effectively. Based on this survey, I can only conclude that EMD projects are far more likely to experience issues rather than AD, LRIP, and Production projects.

An Alternate Categorization of Project Types

The categorization of projects as AD, EMD, LRIP, and Production may not provide the best perspective on the relative work scope and risk of various projects. Here, five different categorizations are defined to capture the strategic significance and development complexity in the hopes of observing a correlation between the level of "Red/Yellow" projects with a particular project type and quantity. Note, these project types and have been adapted from definitions previously defined by Wheelwright and Clark[7] and Ulrich and Eppinger[8]:

- **Research or Advanced Development Projects:** Involves the invention of new science, technology, and/or new know-how to be applied to future product/system development projects
- **Platform Projects:** These are platform or core development projects. They utilize advanced or new technologies and typically have a very long design life, sometimes decades, and are the source for several follow-on derivative projects. These projects tend to be more complex and require considerable level of application domain and experienced resources within the organization. They are generally very strategic since they serve to establish market position for new DoD procurements.
- **Derivative Projects:** These are projects, sometimes referred to as incremental projects, which are derived from existing systems, products, and technologies. They tend to require a lesser demand for application domain resources than Platform projects since the technology/product is based on a majority of established capabilities. As well, the projects tend to be less complex and serve to maintain market position.
- **Follow-On Projects:** These are projects, which either extend services of existing contracts and/or require additional hardware/software to be delivered to the target customer. Examples are sustaining activities, depot service, studies for applications, production, etc. They tend to be less complex to the degree that products and technology have already been proven.
- **Breakthrough Projects:** Involve creating 1st generation of an entirely new product or system. They are breakthrough because the core concepts and technologies break new ground for the organization. Often, breakthrough projects do not require a high level of application domain or developmental experience since the effort represents a new endeavor for the organization.

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[7] Steven C. Wheelwright and Kim B. Clark, "Revolutionizing Product Development", The Free Press, 1992, Chapter 2.

[8] Ulrich and Eppinger, "Product Design and Development", McGraw-Hill, 1995, Chapter 3.

A cross-reference matrix for the project categories and types is shown in Table 2.

Table 2. Cross-Reference Matrix for Project Categories and Aerospace Project Types

PROJECT CATEGORY	AEROSPACE PROJECT TYPE
Research and Advanced Development	AD
Platform	EMD
Derivative	AD, EMD
Follow-On	EMD, LRIP, Production
Breakthrough	AD, EMD

Using this project categorization, the MC business area projects are mapped over time to get a different perspective on the project mix in the pipeline, which is shown in Figure 8.

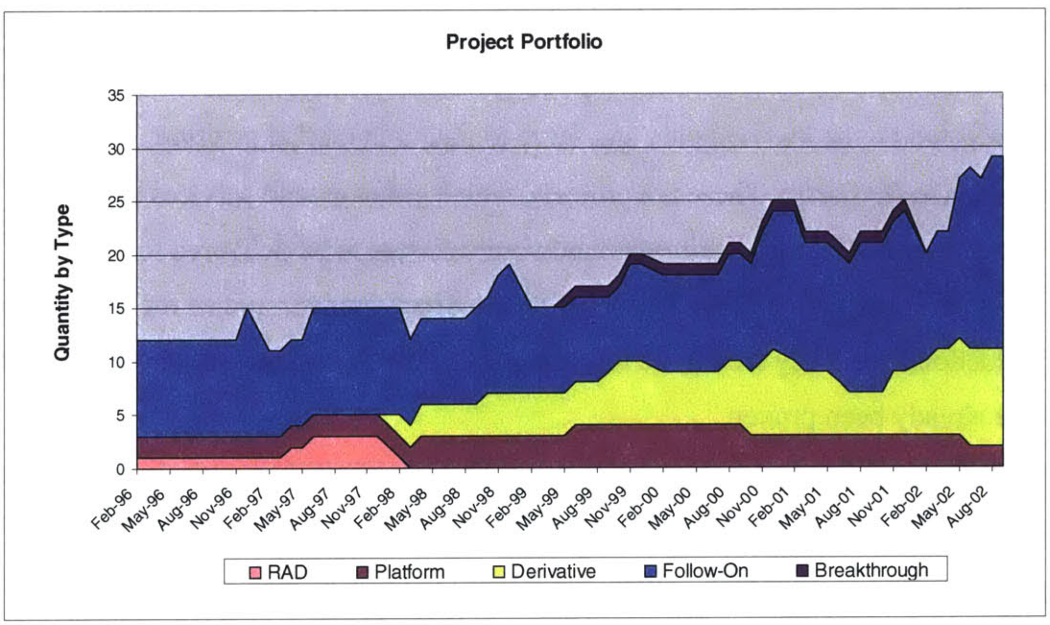

Figure 8. Alternate Project Categorization of the MC Business Area Project Pipeline

While the alternate project characterization is also interesting, unfortunately, it fails to yield an apparent correlation between the number of projects types and the level of "Red" or "Yellow" projects especially over the time period from 1996 through 1999 where there was a distinct increase in the level of troubled projects. Therefore, one cannot conclude that the level of troubled projects can be directly attributed to the number or type of projects being executed by the organization. As such, additional research was performed to ascertain other potential causes for poor project performance.

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Chapter 3

Perceived Causes for Poor Performance

Across the enterprise, considerable effort has been made to understand the causes behind trouble projects and to reduce the CoPQ. In fact, reducing the number of "Red" or "Yellow" programs has been a company wide objective for the last several years as it is viewed as the key to improving customer satisfaction, becoming a preferred developer, and achieving business growth. Here, the company's principal findings and trends are discussed.

3.1 Central Causes of Fire Fighting

The company has performed several surveys, independent reviews, and management level assessments over the last several years to identify and implement business process changes to mitigate the number of troubled projects.

There are six principal areas identified as causes for why projects go poorly:

- Bid and Proposal
- Planning and Execution
- Staffing
- Process
- Subcontractor (Supply Chain) Management
- Requirements Management/Integration & Test (Systems Engineering)

<u>Bids and Proposals</u>

Poor bids and proposals relate to conditions when project bids are too aggressive and are priced to win rather than to execute. Pricing or bidding to win is often driven by the desire to win new business combined with limited funding provisions and high product performance needs of the customer. Aggressive customer needs, high levels of competition, technology maturity optimism, and over-confidence in the development process can drive management to a more optimistic set of proposal assumptions. In these cases, projects may be bid with best-case productivity and quality assumptions, i.e., low rework/iteration needs and a high-level of technology readiness.

Furthermore, the proposal team may assume an allocation of the organization's best staff (experienced managers, critical engineering skills, and application domain expertise) without full recognition of conflicts that will arise with on-going projects to which the same staff is already assigned. In most cases, the proposal team is often different than the execution team and key assumptions are not always transferred to the project team executing the project, or are not carried through, or are just not realized such as technology maturity, reuse levels, staffing allocations, rework (quality) etc.

Planning and Execution

Planning and execution highlights projects that are not fully planned in detail before works begins and/or boilerplate project plans are put together simply to meet company process criteria and are not truly used. Sometimes, there is failure to adequately plan the critical path schedule and/or to put in place provisions to manage it. When detailed plans are in place they may be quickly abandoned when fire fighting occurs rather than re-planning the project.

Risk mitigation plans may be limited or lacking particularly early in the program. At times, the risk mitigation testing may be often combined with formal customer tests leaving no time to remedy a product or system shortfall if a problem occurs.

Other elements of poor planning included:

- Key functions within the Integrated Product Teams (IPTs) are eliminated to save "money", often a short-term gain but a long-term loss.
- Failure to meet exit criteria before starting new project phases.

- Inadequate planning for staffing (skill mix, duration, and security clearance requirements), test resources, integration & test, and verification/validation

Staffing

Staffing issues principally involves the lack of available staff having the right experience level and critical skills to execute the project as planned. Criticisms are that assigned project management and engineering staff lack critical experience in the type of project being executed, i.e., AD, EMD, LRIP, Production and/or lacking experience in the technology being applied. As such, staffing gaps typically exist on two levels: application domain/technology and project execution/management skills. Also, personnel reassignment or "pulling" from one projcct to work another leaving the original team short handed often occurs to support project fire fighting and unplanned business development activities.

Process

Process issues reportedly deal with either too much or too little process. In the case of too much process, the process rigor is over-bearing for the value delivered and results in impeding the development process. On the other hand, too little process leads to incomplete work hand-offs that materialize as defects in the down-stream phases of the project.

Subcontractor (Supply Chain Management)

The failure to assess a subcontractor's ability to perform: experience, staffing, capital equipment, financial resources, and process.

In addition, there is a failure to treat subcontractors as team members. The project team may not adequately address subcontractor issues. As one manager put it, there is sometimes the view of "Their side of the ship hit the iceberg, not ours." There can be a failure to identify problems early on as well as a lack of project plan review and risk mitigation. Finally, poor and/or late requirements flow down to subcontractors is also identified as a symptom of poor supply chain management.

Requirements Management/Integration & Test (Systems Engineering)

Systems engineering issues associated with poor or lacking systems engineering rigor such as: failure to flow down requirements, requirements changes late in the project, failure to recognize the full impacts of changes and delays early in the project, failure to adequately provide for verification and validation, accepting customer changes without team reviews and agreement, failure to document customer requested changes, shortcut subsystem integration tests to "make up" schedule.

It is important to note that one or a combination of these factors can contribute to poor project performance and to varying degrees as well. Fifteen major "Red" projects are surveyed to understand the frequency of these factors. A Pareto chart showing the results is provided in Figure 9.

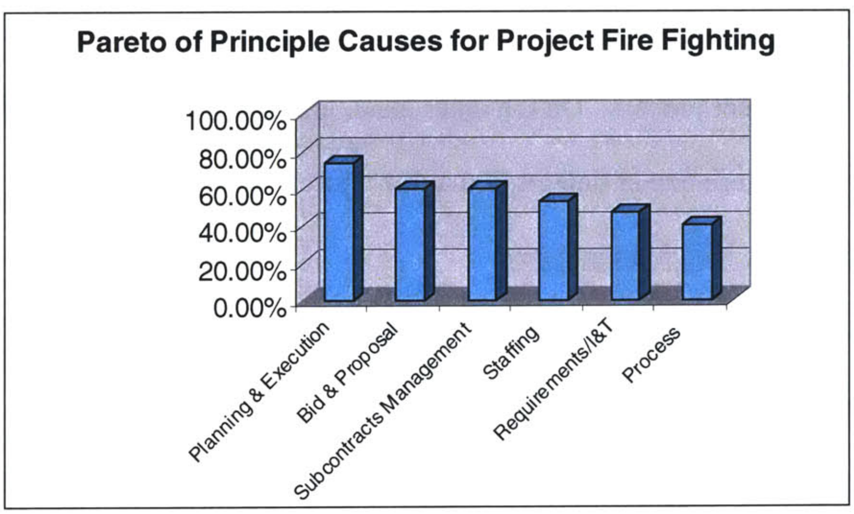

Figure 9. Survey of Fire Fighting Causes Across 15 Major Projects

The results show that 73% of the projects suffered from poor planning and execution to some level. 60% of the projects identified poor bid/proposal efforts and insufficient subcontract management. 53% of the projects identified poor staffing and lack of proper staff mix. 47% of the projects experiences some level of requirements and integration & test issues and 40% highlighted poor application of process as a cause of fire fighting.

3.2 When Does Fire Fighting Typically Begin?

Eleven projects from the MC business area were reviewed to determine at which phase in the project development did the project turn from "Green" to "Yellow" or "Red". The product/system development process along with where the eleven projects declared problems is summarized in Figure 10. Based on this sampling, the results show that projects, which get into trouble, tend to do so late in the project. None of the projects were "Red" or "Yellow" in the up-front phase of requirements/concept development and the majority of did not realize issues until integration & test or product build.

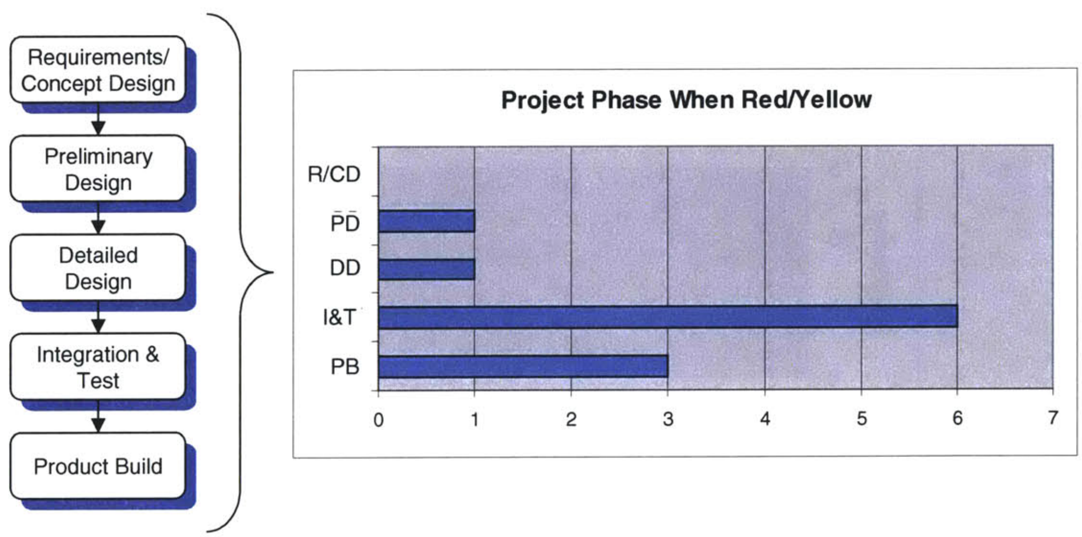

Figure 10. Where in the System Development Process Do Projects Turn "Red" or "Yellow"?

3.3 How Long Does Fire Fighting Last?

A review of the monthly project status for the five core business areas over the 1998 through September, 2002 time period indicates that, in general, once a project turns "Red" or "Yellow", it will continue to remain so for several months rather than changing its status month to month. In fact, the average fire fighting duration is 8.5 months with a standard deviation of 10.2 months. This shows that once a project gets in trouble and begins fire fighting it tends to continue in that mode for a considerable period of time. This also implies that the level of fire fighting is quite severe since it takes several months to remedy the problems being experienced. The histogram in Figure 11 provides further insight. The graph shows the frequency and cumulative percentage of how long it has taken projects to recover and turn "Green". It can be seen that a large percentage of the projects recover within 12 months, however, there are a number of projects, which take 18 or more months to recover. Of note is that these projects also tend to be the largest and most strategically important for the enterprise. Unfortunately, such levels of fire fighting for the most important projects destabilize customer satisfaction and can impact existing and new business opportunities for extended periods of time.

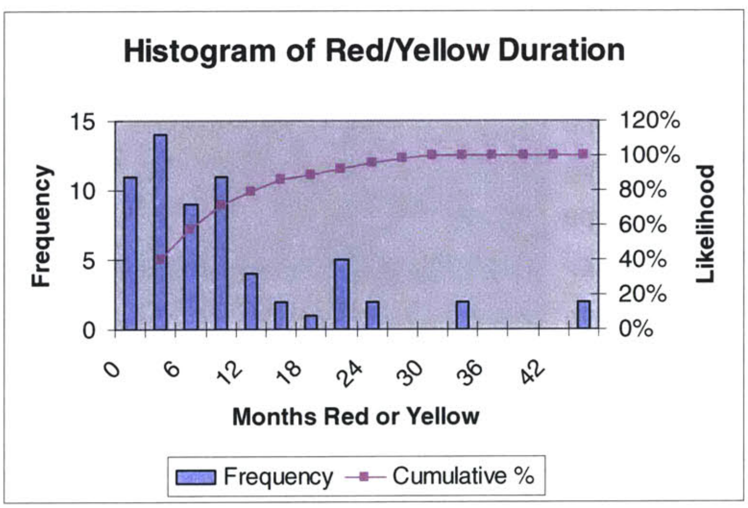

Figure 11. Histogram of Red/Yellow Durations for Projects Within the Five Core Business Areas (1998 thru Sept 2002)

Finally, such a metric may be useful for business area management in gauging the organizations capacity for executing projects. Just as the number of "Red" or "Yellow" projects is an indicator of an organizations capacity to execute a given level of work within the project pipeline, considering current execution capacity in terms of both the number of troubled projects as well as the organizations speed at which it can put out fires and recover from project issues could be used in decision making with regard to business development and project portfolio planning.

3.4 How Fires Are Put Out?

There are four primary ways that project issues are corrected and resolved and any one or combination of them will be employed depending on the severity of the problems encountered:

- Corrective actions worked within the organization/project team
- Technical performance relief is granted by the customer
- Schedule relief is provided by the customer
- Additional funding is provided by the customer

Corrective actions within the organization or project team include staff increases, leveraging expertise across the organization/enterprise, and development of corrective action plans. These actions often include the re-assignment of critical personnel between projects and/or increases in staffing levels. Ideally, such actions should take place before problems arise, however, in many cases they often only take place after the issues are apparent and the fire fighting is well underway. So goes the adage stated by one manager, " We never seem to have enough money to do things right the first time but always seem to be able to find the money to fix projects after they go "Red"". Corrective action steps within the project are always the first step in correcting issues but project history indicates that this is typically only successful for a minority of troubled projects. In fact, most project execution issues require some level of relief from the customer.

Technical performance relief is often necessary either because certain technical performance parameters are identified as high risk or unachievable within the cost/schedule constraints of the project. Ideally, such actions for performance relief should be identified early in a project before the detailed design is complete and significant material purchase commitments are made. Unfortunately, what is observed is that these actions can sometimes take place late in the project well after the detailed design is complete when the system/product is in integration & test or early production and there is little or no cost or schedule reserve remaining in the project.

Increased funding and schedule relief are usually the last resort and necessary when sizeable execution troubles arise. In worst-case projects, severe levels of fire fighting and project performance issues force the project to be re-structured or re-baselined. In these cases, the project issues are so great that there is no choice but to increase funding, delay schedules, and re-plan the entire project. Such situations are obviously highly undesirable as it causes severe impact to the customer, as additional funding must be acquired through considerable DoD scrutiny and restructuring of other contracts is often required. Furthermore, the company's reputation is tarnished for not meeting its commitments.

Seven major projects were reviewed to determine the combination of actions that were necessary to return to "Green" and resolve execution issues. Table 3 shows what actions were required by project

Table 3. Recovery Actions from 7 Major Projects

Project	"C"	"I"	"R"	"ICP"	"M"	"L"	"29"
Project Worked Issues	√	√	√	√			√
Technical Relief	√	√					√
Increased Funding	√	√	√	√			√
Schedule Relief	√	√	√	√	√	√	√

One can see that while most projects corrected some of the issues internally, all required some level of schedule relief and most required increased funding and technical performance relief from the customer. It is then apparent that a majority of projects, which go "Red" or "Yellow", cannot resolve the issues internally as the situation is often over-constrained and some level of outside relief is required. In spite of this, natural behavior and management policies favor resolving the issues internally first and only addressing the customer for relief when the project cannot resolve the problems. Unfortunately, delays in dealing with the source of the impediments serves to only exacerbate the issues.

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Chapter 4

Resource Planning and Allocation

In this section, the resource planning and allocation policies of the enterprise are discussed. Three factors identified as being major contributors to why projects get into a fire-fighting mode: bid & proposal, planning & execution, and staffing behaviors are principal interconnects to the resource planning and allocation philosophies of the enterprise.

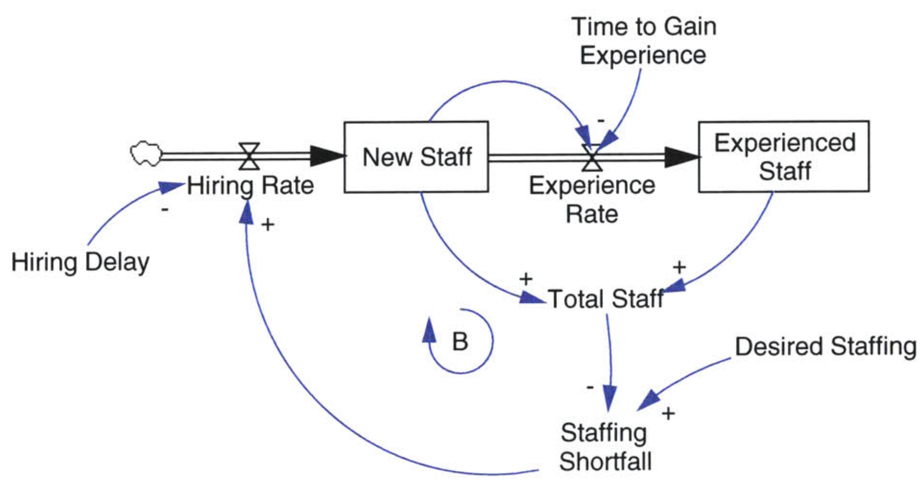
4.1 Resource Planning System

The engineering resource planning system is used as a staffing assignment and forecasting tool whose purpose is to monitor current staffing allocations versus current project needs as well as to make hire/re-assignment/layoff decisions based on projected staffing needs for current and potential future project work.

The system utilizes resource loaded project plans of active projects, staffing estimates from current bids/proposals for new projects, and forecasts for staff needed to support other potential projects in the future. These resource needs are then aggregated by resource discipline to forecast the staffing needs for electrical engineers, mechanical engineers, etc. across the organization. These resource needs are then compared to actual project assignments by business area to highlight whether or not projects have too much or too little staff assigned. Staffing shortfalls are addressed by reassigning staff from projects, which are ramping down or releasing staff and vice versa. Hire/re-assignment/layoff decisions are made based upon staffing forecasts and real-time management input. If forecasts indicate that staffing needs will increase over existing levels, then hiring actions will be initiated. If forecasts indicate a surplus of staff, then re-assignment among business areas may be planned. If the staffing surplus cannot be absorbed, then layoff decisions may be made as a last resort.

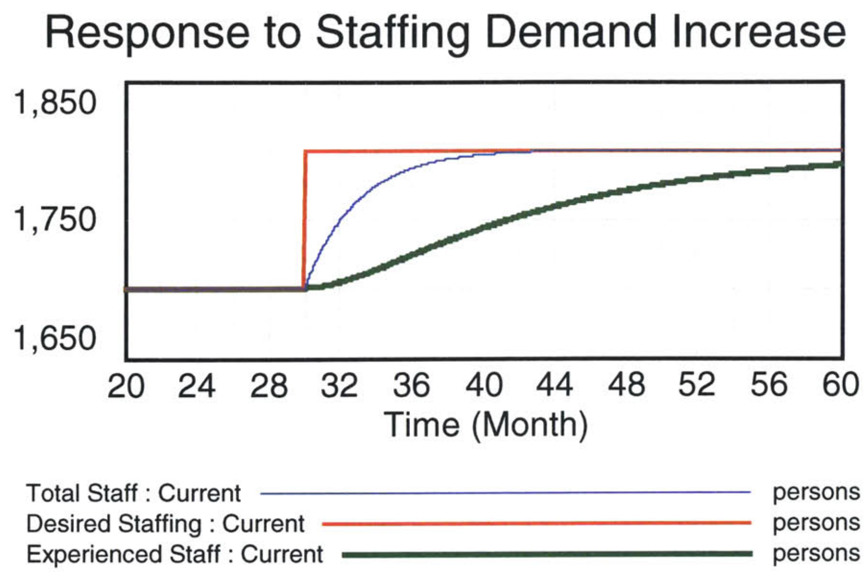
To account for the uncertainty of winning proposed projects and to protect against the down-side risk of having too much staff and having to carry additional expenses or laying off staff, the staffing projections will be discounted to ~90% of the forecasted level. Therefore, if all the currently planned and proposed project-staffing needs were realized, the organization would be over-utilized and there would not be enough staff available. The forecasting policy along with high resource utilization targets (85%-90%) for existing staff will result in considerable tension within the staffing system if actual staffing needs exceed the level planned.

It is clear that this policy favors the downside risk of not having enough work for current staff. However, let us analyze the potential system delays in responding to sudden increase in demand for staffing due to expected and/or unexpected project wins. To do this, the staffing process will be modeled using a stock and flow model adapted from Sterman[9] as shown in Figure 12.



a) Simple first-order model of the staffing system

[9] John D. Sterman, "Business Dynamics-Systems Thinking and Modeling for a Complex World", McGraw-Hill, 2000, Chapter 8, pg 276-277, 470



b) Response to staffing demand increase of 100 at month 30

Figure 12. Simulated Staffing System Response to Increases Staffing Demands

The staffing system is hypothetically modeled as a first-order linear, negative feedback system with explicit staffing goals (desired staffing). The total staff is the sum of new staff and experienced staff and it is assumed that the initial total staff level consists of 1700 experienced staff members and the staffing demand has increased from 1700 to 1800 persons in month 30. This, in turn, creates a staffing shortfall of 100 persons. In response, new staff will be hired at a rate equal to the staffing shortfall divided by the hiring delay. Note, there is a 3-month hiring delay assumed and it is also assumed that it will take 12 months for newly hired staff to become experienced. The hiring delay represents the average time that it takes for the organization to identify the staffing shortfall, coordinate skill needs, initiate actions to hire the new staff, and to actually hire staff.

The behavior of this negative feedback system is such that as new staff is hired and the total staffing level approaches the desired staffing level, the staffing shortfall is reduced and so does the hiring rate to reflect the conservatism associated with the system protecting against hiring too much staff. As such, the hiring rate will continue to decrease until the desired staff goal is reached. The point here is to recognize that the system delay associated with hiring new staff is much longer than intuition would lead most to believe. Using an estimated average 3-month delay time in identifying needs and hiring staff, it takes roughly 15 months to meet the total staffing demands. Furthermore, this delay does not include the time necessary for the new staff to gain experience. As shown in the graph in figure 12, there is an additional delay associated with the new staff gaining experience. If the increase in staffing demands were for experienced staff, there would be significant impacts associated with these staffing delays.

This simple model illustrates the importance of having accurate and timely resource plans for current and future projects since the system is designed to maximize the utilization of all available staff. If project plans or proposals are under-stated in terms of staffing needs and/or unplanned work "pops-up" within projects due to scope increases, changes, or un-anticipated rework, there would be substantial delays in acquiring new staff with the proper skills required to execute the work. Therefore, it is extremely important to spend to necessary time to make sure that resource plans are accurate and specific so that the system can have time to respond and provide the necessary resource skills.

While accurate resource forecasts are highly desirable, it is recognized that this is very difficult to achieve in the Aerospace business where the majority of projects are competitive DoD procurements. Unlike the commercial sector where projects can be planned well in advance, future projects in the Aerospace environment are probabilistic in nature. Each project is won or lost based upon competitive proposals and are often awarded late to initial schedules due to shifts in the DoD budgets and procurement plans. The projects are also subject to shifts in scope communicated sometimes as late as the time of contract award leaving little time for the organization to respond.

4.2 Perceptions within Management

At the time of this research, the company had just completed a company-wide Baldridge assessment as part of an on-going continuous improvement initiative. One of the findings relative to "work systems" was the need to improve staff planning and allocation policies and processes. The assessment noted:

"Although used frequently, the Workforce Planning Process is used only when required by assignment. Reconciliation between business areas and functions is time consuming and not always completed. As a result, the confidence of the management team in the workforce planning process is low. The process considers headcount only and does not consider strategic skill needs."

The resulting action proposed by the assessment team was entitled – "The Right People, Right Place, Right Time" thereby highlighting the principal complaint from many project managers. The central theme is that in spite of the view that business and development processes have improved there continues to be many instances where projects are either short staff or have staff with the wrong skill mix. As highlighted above, the primary issues with the Workforce Planning Process (WPP) is that it is normally performed by direction rather than part of the standard business process. As a result, the staffing plans used in the forecasting/planning are often incomplete or not accurate. Furthermore, the plans only capture the headcount of various staff disciplines, i.e., the number of systems engineering, electrical engineering, etc. and do not capture critical skills such as years of experience, technology expertise, and security clearances required. Therefore, the WPP yields a plan that assumes that the staff is fungible within a discipline. In addition, both functional managers and project managers do not have high confidence in the workforce plan as it does not reflect the true needs of the organization accurately.

Several mid-level and senior-level functional and business area managers were interviewed to understand the various perspectives concerning resource planning and allocation within the organization and are summarized in the following paragraphs.

Resource Planning

The general view from those interviewed confirmed that although the WPP is believed to be adequate to assess staffing needs for generic discipline categories and a useful tool for understanding trends, it is believed to be insufficient for addressing specific skill and attribute needs. Many indicated that, historically, there have not been issues with meeting generic skill needs but there are almost always issues in addressing critical and specific skill needs. One manager commented, "the fallacy in the system is that it does not account for the "bottlenecks" created by the demand in critical skills since planning only considers function".

Most individuals commented that the process continues to improve but there is still much progress to be made. Another manager noted, "workforce planning is one of the hardest things we do in engineering since development projects deal with high variability in terms of unforeseen technological complexity as well as project volatility driven by added scope, early awards, changes, delayed awards, etc. which all contribute to variations in the base workforce plans. Rapid changes in technology have driven the business to be more dependent on specific skills in many areas, which are difficult to estimate, so shortages in specific/critical skills are common". These conditions combined with a staffing policy that establishes a desired staffing level below the forecast while maintaining a high workforce utilization means that projects will continue to feel the pinch in the availability of people.

From a process viewpoint, several managers noted that workforce planning takes too long (approximately 8 weeks is needed to complete a workforce forecast). Due to the variability in staffing needs, the forecast changes as soon as it is written down. The manpower forecast is viewed as a useful tool to provide trends but does not help in dealing with be new demands for talent that need to be met everyday.

Perhaps the most insightful feedback was that the WPP was considered a static process worked periodically rather than an on-going process worked continually. One business area manager commented that the WPP is the scapegoat and the real weakness is in the process. Project teams, comprised of both business area and functional managers, need to take an active role and on-going commitment in addressing staffing needs. He estimated that only 5% of the projects work staffing as rigorously as they should and those that do so are far more successful than others who don't. On the other hand, project teams cite that they were too busy executing projects to take time to plan staffing. This is perhaps a natural tendency of the organization and its technology driven culture to have an inherent bias towards working the more exciting and tangible development issues of the project rather than planning for staff.

Finally, several managers criticized the lack of an effective process to develop critical skills to mitigate the risk of resource bottlenecks. Typically, it is the same set of individuals assigned within specific business areas are sought after particularly when project are in a fire-fighting mode. Wheelwright and Clark[10] describe this phenomena as being a result of over commitment of available development resources, which results in a handful of key individuals being continually sought out for multiple projects. Such a condition is indicative of situations

[10] Steven C. Wheelwright and Kim B. Clark, "Revolutionizing Product Development", The Free Press, 1992, Chapter 4, pg 90.

where aggregate utilization is 100% or more and those key resources become the bottlenecks in the projects to which they are assigned.

Resource Allocation

A common critique of the resource allocation process is the lack of an established priority system to be used by functional and business area managers in determining where staff ought to be assigned based on the business priority and strategic importance of a project. The current allocation policy is informal and favors business area "possession" of staff. That is, if staff has already been assigned to a project/business area then it is very difficult to reallocate that resource to a different project outside the business area. Furthermore, staff personnel tend to remain with a project/business area well after a project assignment is completed because business area managers have tasked them with un-planned follow-on business pursuits and/or un-planned efforts on the original project. As such, the informal system relies heavily upon the ebb and flow of projects to facilitate the re-allocation of staff from project to project. At times, decisions to re-allocate staff are made based on priority but these decision processes are often lengthy as they involve considerable coordination between mid-level and sometimes senior-level management. Such delays serve to consume management attention and impact on-going projects as well. Many of the resource allocation issues stem from excessive demand on critical skills and the lack of "bench strength" when project issues arise and/or when there is an increase in projects within the development pipeline.

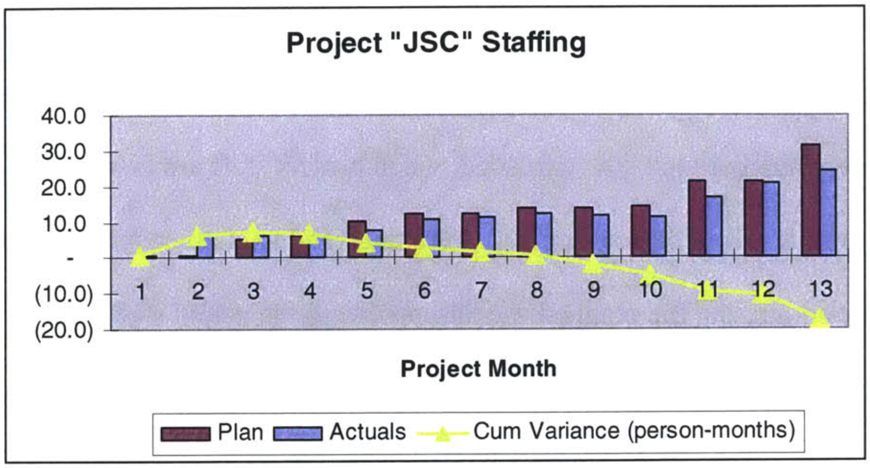
4.3 Staffing Queues

Given the informal resource allocation policy which relies heavily on the ebb and flow of project starts and completions combined with the variability in resource plans and the background described regarding project fire-fighting and associated cost/schedule overruns, the existence of staffing queues[11] were researched. The existence of sizeable staffing queues are indicative of project overload [12] particularly in light of management feedback that project schedules are rarely renegotiated, i.e., extended, when project staff are assigned late to plan.

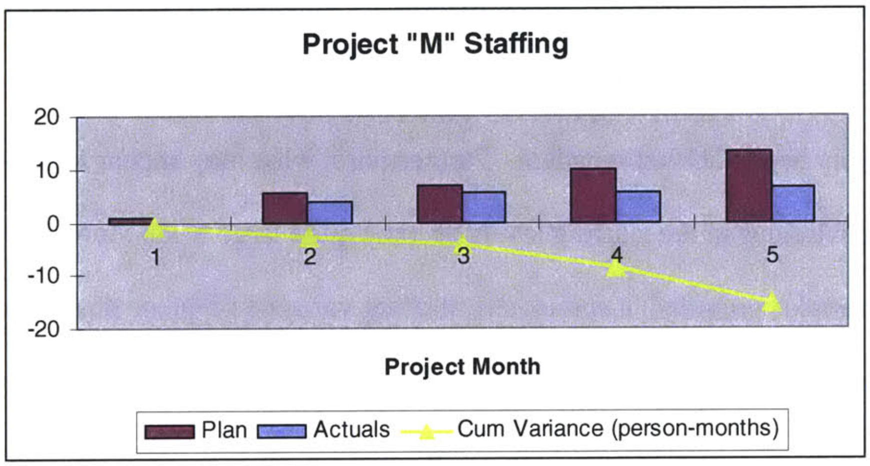
Staffing profiles from several projects were analyzed to characterize the delays in assigning staff by comparing the planned staffing profile to the actual staffing profile for up to 13 months (based on the availability of data) after the planned project start date. The results for three sample projects are shown in Figure 13. Here, one can see clear evidence of staffing queues since the projects are waiting several months for requested staff. Assuming that these project plans were consistent with the workload required to complete the project on time, these projects effectively began behind schedule. Furthermore, what may appear to some as being small monthly deviations in the staffing levels become quite large when viewed on a cumulative basis. In the examples provided, a cumulative staffing variance or queue size (calculated as the area of the difference between the cumulative staff requirement vs. time and the cumulative staff assignment vs. time) exists for Project "JSC", "M", and "S" of 17.4 person-months after 13 months, 15.3 person-months after 3 months, and 30.6 person-months after only 7 months respectively.

[11] Staffing queues are staffing requests waiting to be filled. A queue is a waiting line.

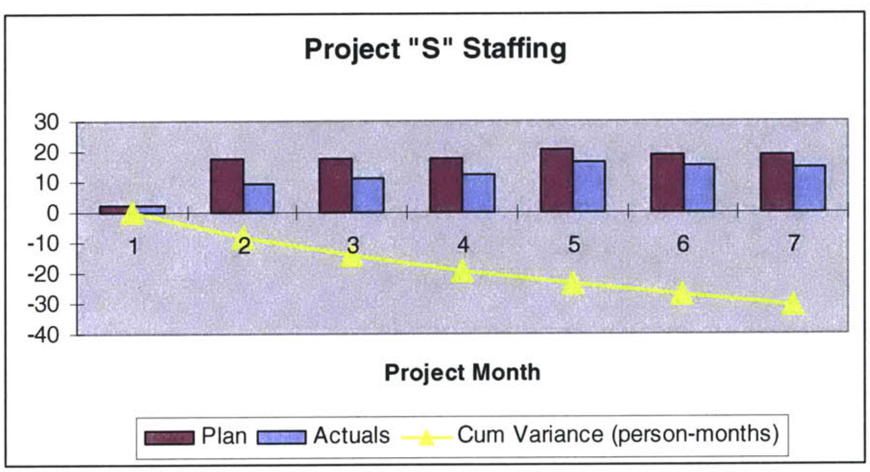
[12] Preston G. Smith and Donald G. Reinertsen, "Developing Products in Half the Time", Van Nostrand Reinhold, 1991, Chapter 11, pg 196



a) Project "JSC" Staffing Queue



b) Project "M" Staffing Queue



c) Project "S" Staffing Queue

Figure 13. "Start-up" Staffing Delays (Actual vs. Planned) for Three Sample Projects

These results were further confirmed by one senior manager where he noted, "our historical performance in staffing projects to their start-up plan is abysmal". Another business area manager commented that such delays in allocating staff to new projects create a bow-wave expenditures and work to recover in the future that aren't always reflected in the forward going project plans thus there will be no additional resources planned to cover them.

Based on this information, it is apparent that some level of project overload exists particularly when two or more projects within a particular business area overlap resulting in excess demand for critical skills and application domain expertise.

The implication of queues in the product development can be significant since it is counterintuitive to common deterministic views of the relationship between cycle time and capacity utilization. Reinertsen[13] provides a very informative and insightful discussion of queues in product development that are worth summarizing here.

First, I will look at the development process as a compilation of queueing systems[14]. A queueing system consists of a waiting line and a server. Staffing queues can be represented as project tasks from new projects that are waiting to be served by project engineers as illustrated in Figure 14. Here, I represent a project as a queueing system structure comprised of multiple queues, each filled with project tasks which are served or performed by engineers of various disciplines, e.g., systems engineer, electrical engineer, mechanical engineer, etc. depending on the task type. The underlying assumption is that the tasks arrive at random about some average arrival rate and are random in duration about some average service rate since some tasks take longer to perform than others.

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[13] Donald G. Reinertsen, "Managing the Design Factory", The Free Press, 1997, Chapter 3 – Entering the Land of Queues.

[14] D. Maister, "Note on the Management of Queues", Harvard Business School, 9-680-053, March 17, 1995. This is a useful paper, which also discusses the nature and management of queues.

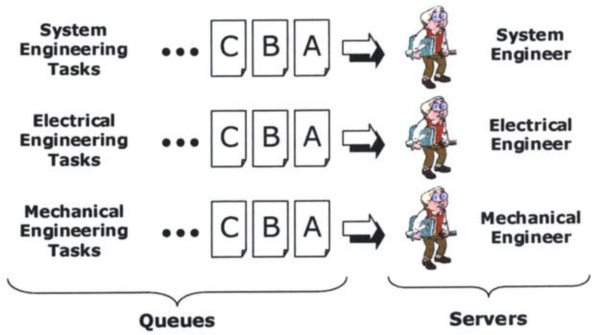

Figure 14. Queueing System Structure for Product Development

Given this simplified structure, one can model each type of project task as having a single server. The queueing curve for this situation is shown in Figure 15. This provides critical insight into the cycle time effects of such a circumstance. Two important properties of queueing systems become evident: 1) the system will have a tendency to overload below or near 100% utilization and 2) there is a non-linear relationship between utilization and queue length in the system.

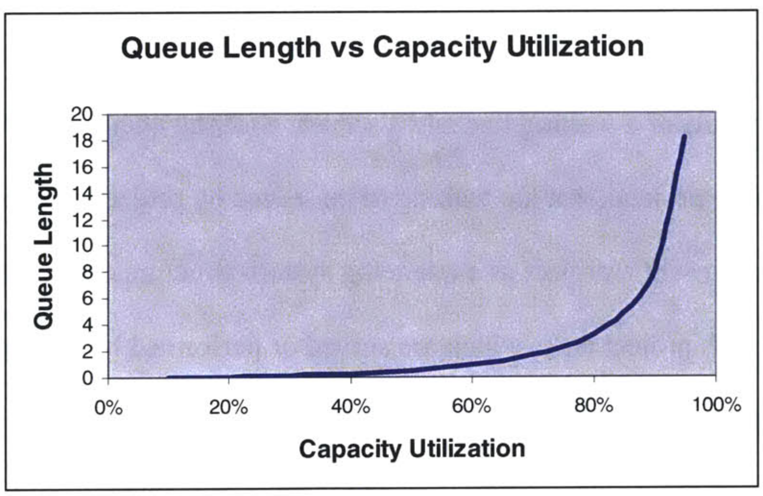

Figure 15. Queue Length vs. Capacity Utilization for a Single Server System

One can see that as the utilization of the server (defined as the task arrival rate divided by the service rate) increases, the queue length or delay time to perform the tasks will increase non-linearly. This phenomenon is counterintuitive to most managers since overload is not expected until 100% utilization is reached. The curve also shows that by reducing queue length, delays in workflow can be substantially reduced thereby improving project schedule performance. For example, a 5% reduction in utilization from 95% to 90% will reduce the cycle time by more than 50% since the task queue length will be cut by more than one-half. Reinertsen highlights that two primary factors impact queues: capacity utilization and variability of task arrivals and durations. While zero variability of tasks could eliminate the existence of queues in product development, he argues that this is impossible due to the inherent uncertainty of the development process. Rather, most product development firms stand to gain the most advantage from adjusting the level of capacity loading on their development organization.

It is important to note that the existence of queues can be either good or bad depending on where they exist in the development process or project. The only bad queues are the ones on a project's critical path as they will delay the project and result in negative cost and schedule variances. In the case of the organization being studied, so called "bad queues" are likely to exist if the organization consistently experiences delays in assigning staff to new projects in a timely manner since many early tasks within a project are inevitably on the critical path.

Given an understanding of how queues form and behave along with their associated dependencies, strategies for controlling queues and maximizing project cycle time can be employed, namely, increasing development capacity and reducing or managing demand. Examples of specific strategies include: controlling task flow rates, reducing variability and increasing consistency in the development process, or using control strategies such as queue monitoring or capacity planning. As a start, it would appear that this organization would benefit from creating and monitoring staffing queue metrics, similar the charts in Figure 13, for new and existing projects as a means for assessing execution capacity and as an indicator for future project delays.

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Chapter 5

Project Execution Capacity and Overloading

In this section, I explore the subject of project or product/system development capacity and project overloading in more detail to understand the indicators and behaviors associated with the subject. A causal loop diagram is developed to capture one mental model of the key business processes and behaviors which support the hypothesis that project overload is a vicious cycle for the aerospace organization being evaluated and possibly the industry itself.

Project execution capacity is defined here as the ability to execute a project or projects at a defined cost and schedule goal that delivers a satisfactory level of product/system performance to the customer. Project overload exists when either too many projects exist within the project pipeline for the available development resources or project cost, schedule, and/or performance objectives are not compatible with the development capability of the organization. In either case, the result will be project fire fighting as the organization will fight to mitigate resulting cost, schedule, performance shortfalls.

Several authors have written about the subject of project overload and the need for project pipeline management. Smith and Reinertsen[15] reported that the issue that comes up most often when working with companies in addressing problems plaguing their product development process is project overload. Companies invariably believe that they have too many active projects going at any one time but have difficulty deciding how many is too many? They

[15] Preston G. Smith and Donald G. Reinertsen, "Developing Products in Half the Time" Van Nastran Reinhold Chapter 11

describe three indicators for identifying the existence of project overload: high individual work loads, an ever-increasing project list over time, and delays in starting new projects. The project load myth that profits will continue to increase as more projects are added to the pipeline is challenged. An example is presented which shows that profits actually decrease as projects are added beyond organizations capacity.

Wheelwright and Clark[16] studied the over commitment of development capacity and reported that over commitment will result in projects being much later that participants have planned in their product proposals. Also, there is a tendency for project execution issues to spread to other projects when there is no slack available as resources will likely be taken from other projects to correct issues. They argue that in most organizations, management of development efforts are too focused on individual projects and should be more focused and engaged in developing and managing an aggregate project plan for the organization that includes consideration of what projects will be authorized over time, which resources will be applied to them, and how resources will be developed to improve productivity and capacity in the future.

Repenning [17],[18] has studied why many firms struggle to effectively execute their desired development process and often enter into a mode of continuous fire fighting where unplanned resources are pulled from projects in their upstream phases to projects in their downstream phases resulting in low aggregate performance for the firm. He develops a hypothesis and an associated system dynamics model to explain the existence and persistence of fire fighting in a multi-project development environment. His analysis suggests that fire fighting can be self-

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[16] Steven C. Wheelwright and Kim B. Clark, "Revolutionizing Product Development – Quantum Leaps in Speed, Efficiency, and Quality", The Free Press, 1992, Chapter 4, pg. 86-90.

[17] Nelson P. Repenning, "A Dynamic Model of Resource Allocation in Multi-Project Research and Development Systems", System Dynamics Review Vol. 16, No. 3 (Fall 2000): 173-212.

[18] Nelson P. Repenning, "Understanding Fire Fighting in New Product Development", Journal of Innovation Management, March 2001.

reinforcing and that multi-project development environments are highly susceptible to this phenomenon and that current methods of aggregate resource and portfolio planning may be insufficient.

Reinertsen[19] states that basic management instincts in engineering development sees excess engineering capacity as waste and will start more projects to maintain high utilization which ultimately leads to project overload. This behavior is in contrast to manufacturing where there is a common understanding regarding the need for excess capacity. Over emphasizing efficiency can prevent managers from seeing the queues created by an overloaded project pipeline.

Adler, Mandelbaum, Nguyen, and Schwerer[20] advocate that the lessons of lean manufacturing can help companies develop new products faster. They state that managers should think of product development as a complex operation with a given capacity and workload rather than simply a list of projects. Their research studied 12 well-known companies who have realized three results from employing process management to product development:

1) Projects get done faster if the organization takes on fewer at a time.
2) Investments to relieve bottlenecks yield disproportionately large time-to-market benefits.
3) Eliminating unnecessary variation in workloads and processes reduce distractions and delays.

5.1 Business Capture Causal Loop

Many of these reported symptoms of project overload resonate with the data collected during this research effort. While not explicitly stated in the sources cited herein, many of these

[19] Donald G. Reinertsen, "Managing the Design Factory", The Free press, 1977 pg 52-53.

[20] P.S. Adler, A. Mandelbaum, V. Nguyen, E. Schwerer, "Getting The Most out Of Your Product Development Process", Harvard Business Review, March-April 1996. pg. 4-15

arguments are biased towards a commercial product development organization rather than an aerospace/military product development organization.

Commercial business firms typically fund product development through funding supplied by the organization itself rather than an external customer. As such, the commercial firm decides directly the type and number of projects it will undertake in a given year or time period and therefore can regulate the flow of projects in the project pipeline.

In contrast, Aerospace business firms typically execute product development funded not by the firm itself but rather DoD (e.g., US Air Force, US Navy, etc.), an external customer. Such product development efforts are usually competitive procurements that result in product/system development contracts. Therefore, the Aerospace firm cannot directly regulate the flow of projects through the development organization due to the uncertainty of actually winning new contracts. These organizations can only make decisions on whether or not to bid on candidate projects and will often plan the project pipeline and associated staffing needs based on probability of win estimates. The pipeline planning can be even further disrupted by delays in contract awards, project starts, and late changes in overall work scope.

Given the evidence that suggests that the organization being evaluated has experienced project overload to varying degrees and that the most prevalent reasons for poor project performance is poor bid/proposals, poor planning/execution, and staffing issues, I hypothesize that project overload exists not because there are too many projects in the pipeline but rather that the resources planned for the projects in the pipeline are inadequate and below a level required to successfully execute the project to the prescribed cost, schedule, and performance constraints. Furthermore, due to the uncertainty of new project capture and timing along with existing resource planning and allocation policies, often the demand of critical resources having specific application domain, technology, and/or development experience exceed the available supply particularly in times of peak development activity.

Based on the project data collected, company interviews, and experience with the aerospace industry itself, a causal loop diagram is developed which captures the significant behaviors and feedback effects which may explain the tendency for organizations to become overloaded and suffer from mediocre project performance. The causal loop diagram is shown in Figure 16.

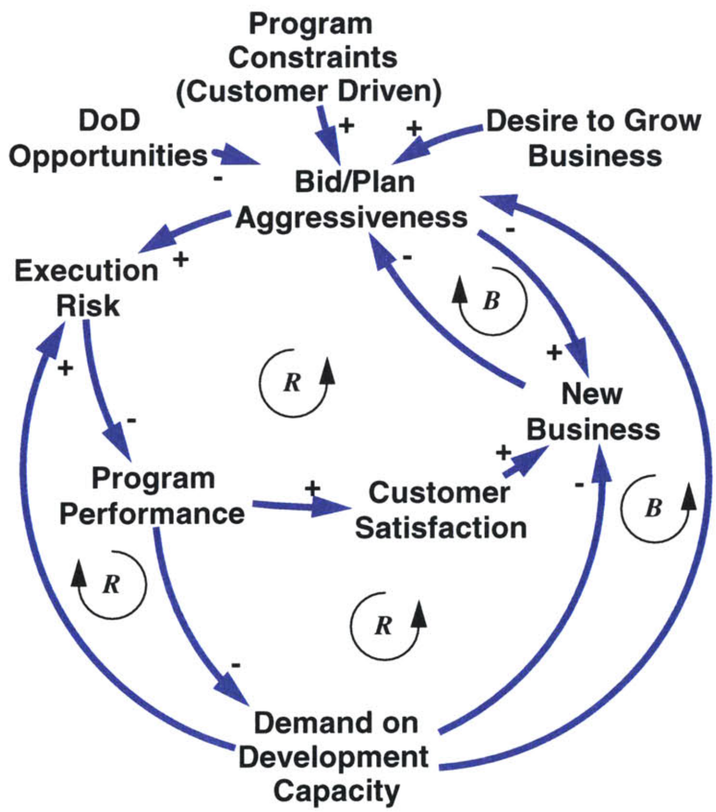

Figure 16. Business Capture Causal Loop Diagram – Relationship Between Business Goals, Bid/Planning, Resource Demands, and Customer Satisfaction.

The causal loop describes three driving factors: Desire for Business Growth, Program Constraints (cost, schedule, performance), and DoD Program Opportunities, which strongly influence project bid and plan aggressiveness. Project bids and plans will tend to become more aggressive as the desire to capture new business increases and/or program constraints become more demanding from the DoD customer. Conversely, as the number DoD opportunities or programs increase, the bid/planning aggressiveness will tend to decrease since specific project wins will not be as critical to achieve business objectives.

There are three reinforcing (positive) feedback loops, which influence poor project performance. The primary reinforcing loop is shown in the center of the diagram and is vicious cycle that promotes negative project performance and low customer satisfaction through the generation of aggressive project bids and plans. As bid and project plans become more aggressive, project execution risk will increase due to the tendency for projects to be underestimated, optimistic, and streamlined from a process standpoint. As execution risk increases project performance will decrease as the realization of risks is more likely. In turn, as project performance decreases so will customer satisfaction, which will result in reduced future business. As new business decreases, the organization will react with more aggressive bids to win new business. Such a cycle reflects a goal of winning new business rather than increasing customer satisfaction to the detriment of the organization. The two other reinforcing loops show the impact to demand on critical resource skills or development capacity and are a direct result of the tendency to increase new business through aggressive bidding and planning. The lower left reinforcing loop is established as a result of poor project performance which shows the impact to development capacity. As project performance decreases resulting in higher/longer workloads and fire fighting, there will be an increased demand on critical skills/resources as they are pulled from other projects or are forced to share their time across multiple projects. This increased demand on critical skills effectively reduces the organizations capacity to execute project work in the pipeline and thereby increases the execution risk of current and future projects. The lower center reinforcing loop represents the impact on capturing new business as the development capacity is reduced through poor project performance. As resources are overloaded with project delays and fire fighting, there are less and less people available to support new business pursuits. This ultimately impacts the organizations ability to understand and influence customer needs, which can lead to solution vs. need mismatches, i.e., lost or missed business opportunities which lead to more aggressive bids.

There are two balancing feedback loops shown which serve to counter the tendency to bid and plan aggressively. The first shows that as bids become more aggressive, there is a short-term increase in new business. As new business is captured and business goals are more closely achieved, the bid aggressiveness will tend to relax resulting in more executable projects. The other balancing loop shows that as the organization recognizes a high demand on resources and limited development capacity, bids and plans will be less aggressive thereby creating more executable projects and improved project performance.

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Chapter 6

Project Dynamics

Impacts of aggressive project bids, poor project plans, underestimated resource needs, limited resource availability, and the importance of having the right people at the right place at the right time for the performance of the product development system and individual projects is explored using two system dynamics models built to analyze the effects of various project and resource conditions along with associated management policies and strategies for improving performance.

The models created utilize a simplified project model construct tailored to be representative of an aerospace development project. The simplified project model is utilized in both a multi-project scenario to emulate a project pipeline of multiple concurrent and/or continuous projects and also in a single project scenario. The basic model structure was adapted from a project model developed by Lyneis[21] and is written using VENSIM™[22]. The models and scenario parametrics are provided in Appendix A and B.

6.1 The "Rework" Cycle

The key element in the project model is the rework cycle, which is illustrated in Figure 17 and summarized herein.

[21] James Lyneis, adapted from system dynamics model "Class4.mdl", ESD.36j - System and Project Management, MIT.

[22] Ventana Systems Inc produces VENSIM™ software. http://www.vensim.com/

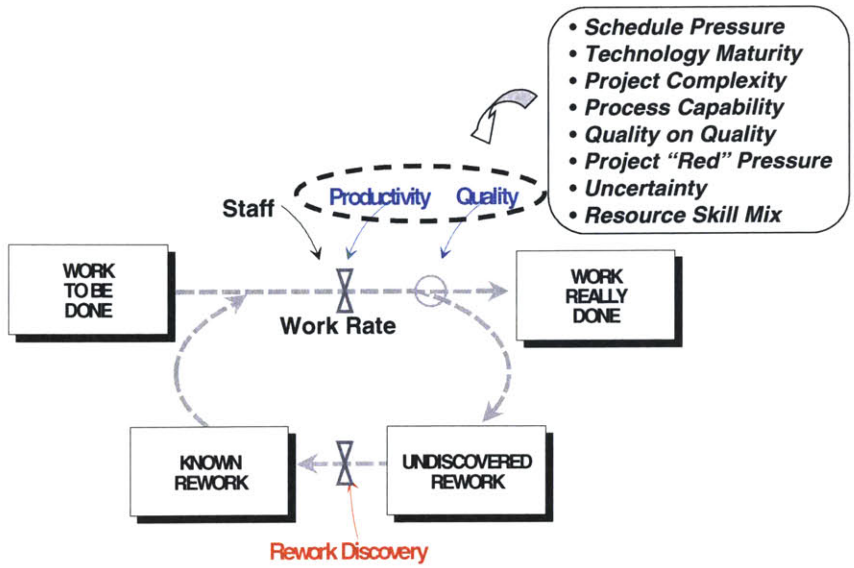


Figure 17. The Rework Cycle – adapted from lecture notes provided by Lyneis[23]

The rework cycle begins with a stock of *Work to be Done* or total tasks to be performed over the course of the project. Work is completed at a rate (*Work Rate*) that is directly controlled by the number of staff assigned to the project multiplied by the worker *Productivity.* As work is completed, it is either *Work Really Done*, i.e., with no defects, or it is work that needs to be reworked that is not yet known – *Undiscovered Rework.* The quantity of *Work Really Done* and *Undiscovered Rework* stocks are dependent on the work quality. The *Work Really Done* is equal to the *Quality* multiplied by the quantity of work being done, where quality is defined as the defect-free percentage of work being accomplished. Thus, the higher the work quality, the higher the level of defect free work that is accomplished. *Undiscovered Rework* is equal to the difference between the quantity of work being done and the *Work Really Done* and is eventually discovered at some rate, *Rework Discovery,* after some period of time. The discovered rework accumulates in a stock of *Known Rework* and is added to the *Work to be Done* stock.

[23] James Lyneis, "Dynamics of Project Performance", ESD.36j – System and Project Management, MIT, Lecture 1, Sept 2002, pg 52.

Factors Which Influence Productivity and Quality

The fundamental drivers in the rework cycle is both productivity and quality as they directly control the amount of work done per worker and the amount of defect-free work that is performed. Low worker productivity and poor work quality are well known factors that plague product development efforts in achieving performance, cost, and schedule objectives. The models include several factors, which influence and degrade productivity and/or work quality over the course of the project. These factors include:

- Schedule Pressure – Acts to positively impact productivity of the work force due to overtime, increased management attention, and possible development process short cuts. Conversely, schedule pressure negatively impacts quality as workers can create more errors due to process short cuts, overtime fatigue, and worker burn out.
- Technology Maturity – Acts to account for quality impacts as a result of immature or uncertainties in technologies used in the project. A less mature technology will tend to result in more rework or design defects as emergent properties are not well understood.
- Project Complexity – Acts to account for quality impacts associated with complex systems and/or project organizations where rework can be generated due to large numbers of interfaces and high levels of complexity.
- Process Capability – Acts to account for quality impacts associated with a tailored development processes. A rigorous development process will tend to result in higher quality than projects that use a process that is less rigorous and substantially tailored.
- Quality on Quality – Acts to account for the quality impacts of rework generated in the upstream phase impacting the quality of work performed in the current project phase.
- Project "Red" Pressure – Acts to account for quality and productivity impacts due to management pressure applied when a project goes "Red". Productivity is impacted since additional unplanned reporting tasks are added causing resources to be pulled from planned tasks. Quality is also impacted due to the additional schedule pressure and workload that is applied to the staff.

- Uncertainty – Acts to account for productivity impacts associated with uncertain or undefined customer requirements.
- Resource Skill Mix – Acts to account for productivity and quality effects associated with the mix of general and experienced staff.

Determining Schedule Pressure and Project "Red" Pressure

Within the project model, work progress is continually monitored to compute and update the estimate to complete (ETC, in person-months) the project work and earned value metrics (BCWS, BCWP, ACWP, SPI, and CPI[24]) common in aerospace project management.

The ETC is in turn used to determine staffing levels required to complete the project on schedule as well as to estimate the project completion date based on the staff currently assigned. If the estimated completion date exceeds the planned completion date, pressure will be applied to the project staff in an attempt to recover schedule performance.

The earned value metrics are computed as the project is being executed to monitor project execution performance, i.e., is it "Green", "Yellow", or "Red"? As described in section 2.1, the earned value metrics are used to monitor project cost and schedule performance relative to a planned baseline of expenditures and completion of work over the scheduled project period. For example, a project with a CPI and SPI of ≥ 1 is on or ahead of the plan for both cost and schedule. If these indices are ≤ 1, it is indicative of a negative variance to the project plan. Should the project fall behind schedule or exceed the expenditure plan such that the indices become less than 0.9, the project will be declared "Red" and both the quality and productivity level of the project will be impacted accordingly as substantial "management attention" and unplanned reporting will follow.

[24] BCWS: Budgeted Cost for Work Scheduled, BCWP: Budgeted Cost for Work Performed, ACWP: Actual Cost for Work Performed, SPI: Schedule Performance Index = BCWP/BCSW, CPI: Cost Performance Index = BCWP/ACWP

Staffing Decisions and Assignment

Staffing decisions to assign and release staff are made on a continuous basis over the course of the project(s) based on each project's demands and the available staff level. The ETC and the project time remaining are used to determine the staffing levels required to complete the project on a desired schedule. The required staffing levels calculated are compared to the current staff level to determine if additional staff is needed or if staff can be released back to the functional organization for reassignment to other projects. In addition, staffing requests may be limited by the hiring policies of the project. For example, maximum-staffing limits can be prescribed based on available funding for the project to avoid assigning staff when budget constraints won't allow for it. Therefore, if staff is needed and the project management policy allows for the request to be made, staff will be assigned only if they are available else the project will have to wait until additional staff becomes available either from hiring and release from other projects.

There are two distinct staffing models that are used for the multi-project model and the single project model respectively. The multi-project model uses a staffing model construct that maintains a single pool of resources, which are assigned to projects on a first-come-first-served basis. If staffing requests exceed supply levels, then the available staff is assigned on a project priority basis, which is used to allocate only a percentage of the available staff to the projects requesting them. The single project model construct consists of two resource pools, experienced staff and general staff, where the general staff becomes experienced over some time period. Each will be described in more detail in sections 6.2 and 6.3.

6.2 Multi-Project Dynamics – "Tipping" in the Project Pipeline

The aerospace multi-project environment is explored for the purpose of understanding the dynamics associated with project planning and aggregate resource planning and allocation. Specifically, the project pipeline will be examined for: impacts of having too few resources available for planned projects, the effect of poor project plans on the project pipeline, and potential management strategies for improving performance when staff levels are limited and/or project plans are underestimated. The analysis shows that product development system *tipping* can occur in an aerospace product development organization. That is, if resources are either under-planned due to aggressive/under-planned projects or unavailable due to delays in the completion of other projects, the organization enters a self-reinforcing condition of cost and schedule overruns.

This analysis represents additional insight to the tipping phenomena originally reported by Repenning[25] as this data is derived from an aerospace product development construct. Repenning's original tipping models[26] employed a project pipeline scenario having a sequence of two overlapping projects consisting of fixed start and stop/launch dates for projects and were biased towards the automotive industry. This work utilizes a pipeline model, which supports multiple projects occurring in any sequence having fixed start dates but variable completion dates thereby emulating the project conditions of the aerospace industry.

In this multi-project dynamics section, the outline is as follows:

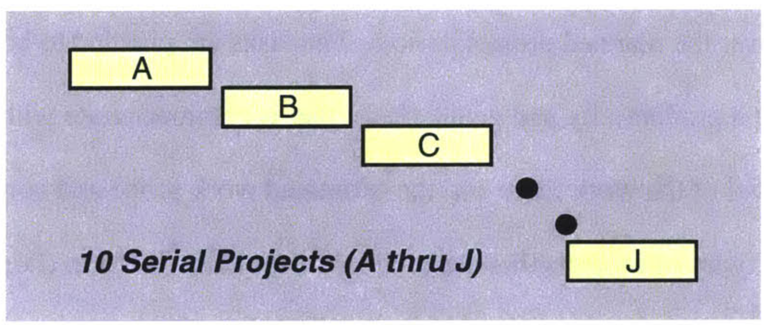
- Project Pipeline Overview
- Key Assumptions
- Scenario 1: Effects of too Few Resources for the Work Planned

[25] N. Repenning, P. Goncalves, L. Black, "Past the Tipping Point: The Persistence of Firefighting in Product Development", California Management Review, Vol 43, No 4, Summer 2001

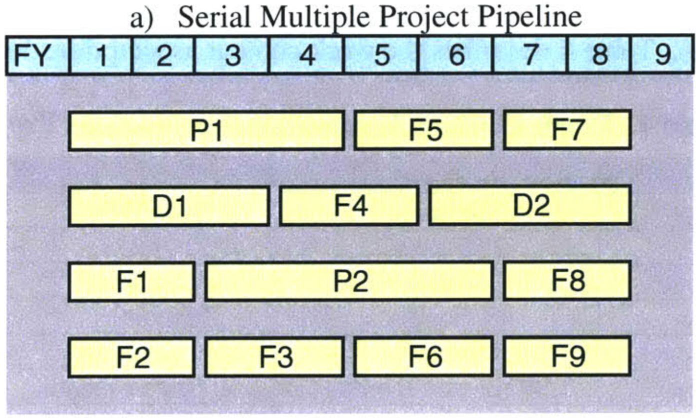
- Scenario 2: Effects of Unplanned Quality Issues
- Scenario 3: Simulation of Concurrent Project Pipeline

Project Pipeline Overview

The project pipeline consists of multiple projects, which can run both concurrently and serially over time. To facilitate the analysis, the projects are modeled as a single-phase project having to complete a number of tasks over a period of time consistent with the rework cycle described in section 6.1. Each project has a fixed start date and a variable completion date that is only reached when the work tasks are actually completed. Illustrations of the project pipelines used are shown in Figure 18.



a) Serial Multiple Project Pipeline



P = Platform Project
D = Derivative Project
F = Follow-On Project

b) Concurrent Multiple Project Pipeline

Figure 18. Project Pipelines

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[26] For more information on these models and Repenning's research, see http://web.mit.edu/nelsonr/www/

Key Assumptions

Project Schedule: The primary assumption in the models is that projects will be managed to begin on their planned start and to complete on their scheduled completion date and management will continually monitor work progress to manage the staff level assigned to the project. While projects are required to start on their planned start date, they can continue for longer than their planned duration. There are two reasons why a project will complete past its scheduled completion date: there are too few resources available to complete the project on time and/or unexpected work tasks or rework is discovered during the course of project.

Project Plans: Each project is planned such that a number of tasks will be completed incrementally over the planned project period. The tasks are planned to be completed by assigned staff at a productivity and quality level that is commensurate with the estimated performance level of the work force and the estimated work scope and complexity of the project. There are three types of projects that are used in the models: Platform (large size/complexity project), Derivative (medium size/complexity project), and Follow-On (medium size/low complexity project). Table 4 describes the work content assumptions for each project type.

Table 4. Work Content Assumptions for Various Project Types

Project Parameter	Platform	Derivative	Follow-On
Total Work Scope[27]	320 tasks	240 tasks	160 tasks
Project Work	288 tasks	216 tasks	144 tasks
Estimated Rework[28]	32 tasks	24 tasks	16 tasks
Planned Duration	48 months	36 months	24 months
Average Staff Level	80 persons	60 persons	40 persons
Total Effort (Cost)	3,840 person-months	2,160 person-months	960 person-months

[27] Total work scope is estimated at an average of 2.6 weeks/task over the planned project duration assuming 4 IPTs (Integrated Product Teams) operating concurrently within the project. Included within the total work scope is the estimated rework.

[28] Rework is estimated to be 11% of the estimated project work.

The project plan assumptions are based upon field research at the organization surveyed to establish a representative set of project conditions to apply to the simulations.

Time to Discover Rework: The time to discover rework is assumed to vary between 18 months and 1 week based upon the fraction of work completed on the project. As the fraction of work completed increases, the time to discover rework or defects will decrease. This assumption is based on the premise that defects in work completed early in the project are not typically discovered until well into the project where product build, testing, and verification occurs.

Staffing for Multi-Project Scenarios: For the multi-project scenarios analyzed, each project will continually monitor work progress and determine the staff level required to complete the project in the time remaining. If additional staffing is required, requests for additional staff will be made. If excess staff exists on the project, staff will be released from the project.

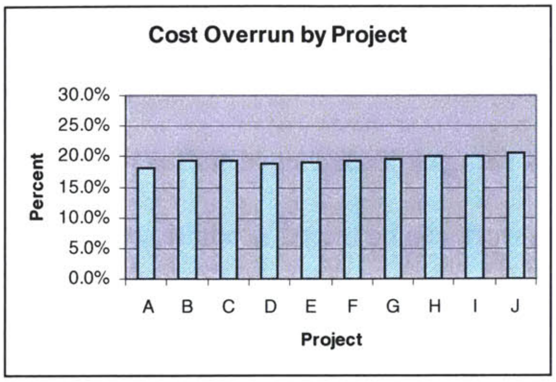
All staff resides in a single resource pool designed to be representative of a matrix organization where product development staff belongs to functional organization that supports many projects. As projects are being executed, staffing requests are filled with resources drawn from a single stock of "available staff". Once staff personnel are assigned to projects, they become "assigned staff" and are not reassigned to other projects unless they are released from the project to which they have been assigned. If the demand for project staff exceeds the staff available then whatever resources are available are allocated based on the relative priority of the project and the number of staff the project needs therefore, the limited staff will be shared across projects based on need and priority.

This particular staffing policy was implemented in the model since it is an approximate representation of the practice at the aerospace organization surveyed. Due to DoD project requirements along with company's management policies, staff is often dedicated to a single project to maximize work efficiencies and to satisfy project constraints. While staff personnel are sometimes re-assigned from one project to another due to fire fighting, career development considerations, project phase transitions, special needs, or unexpected execution issues, it is not believed to change the results presented. In fact, in field surveys several individuals commented that is can be very difficult to get staff reassigned once they have been assigned to a project.

Scenario 1 - Effects of too Few Resources for the Work Planned

In this first scenario[29], the effect of having too few resources available for the project work planned is examined. For this, a project pipeline described in Figure 18a is employed. I assume that there are 10 platform projects of equal priority occurring sequentially using the platform project assumptions outlined in table 3. Each project is planned to complete in 48 months with a 2-month schedule buffer between projects to allow for small schedule delays and natural spacing between project starts. As table 3 highlights, each project is planned assuming that an average staff level of 80 persons is required and available to complete the project on schedule. The model conditions are set to examine a case where the available staff pool only has only 72 persons available – a 10% shortfall in staff level. Beyond being short in available staff, the planned normal productivity and quality levels are assumed. The simulation results of cost and schedule performance of each project are summarized in Figure 19.

[29] A complete listing of the project model (*aerospace multi-project.mdl*) and associated command files (*multiproject slip compare.cmd*) used to run these simulations in included in Appendix A.



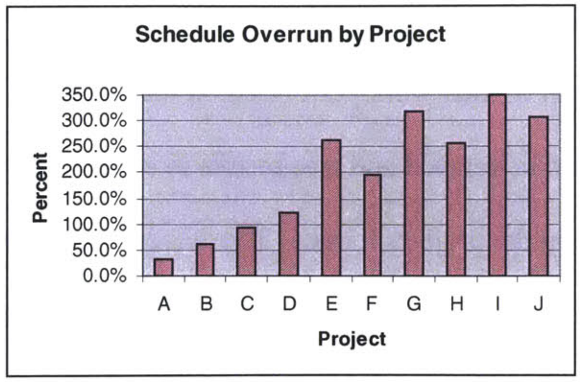


Figure 19. Cost and Schedule Overruns Caused by Resource Shortages

The results show that all 10 projects experience an increasing schedule delay that is equal to the delay in the project start plus the delay associated with having limited staff available for the project itself. The schedule overrun plot shows that the first several projects experience a schedule delay in multiples of ~32% (over 1 year in duration). Projects further down the pipeline experience even longer incremental delays. This is an artifact of the staffing policy where if projects are requesting staff simultaneously then the available staff will be shared between them. In these instances, a project is being delayed long enough that its effective start date is coincident with another project's planned start date, which causes even longer delays. For example, project E's effective start has been delayed such that when staff become available from project D both project E and F are requesting all of the 72 staff workers where the staffing system will share the workers between the two projects which causes project E to be delayed even longer.

In addition, one can see that each project experiences an average cost overrun of approximately 19%. While the schedule delay is expected, the cost overrun is not necessarily expected given that the projects are resource limited. Insight into this effect is apparent by comparing the total amount of work done and the rework level on project "A" for both this resource-limited case and for the case where a full staff level of 80 persons is available as shown in Figure 20. The simulation results shows that when resources are below required levels, the amount of total work performed on the project actually increases thereby causing the schedule to be further delayed and also results in additional costs being expended since staff is required to be kept on the projects longer. The reason for the extra work can be traced to additional rework generated due to the pressure of being behind schedule, also shown in Figure 20. Since resources are not available to complete work at the planned completion rate, the program will go "Red" early in the project inducing management pressure on the project in an attempt to resolve the variance while schedule pressure is also applied to catch up. Both of these management pressures, while aiming to increase productivity actually impact the work quality negatively thus causing the generation of additional rework, i.e., work that must be performed before the project can complete.

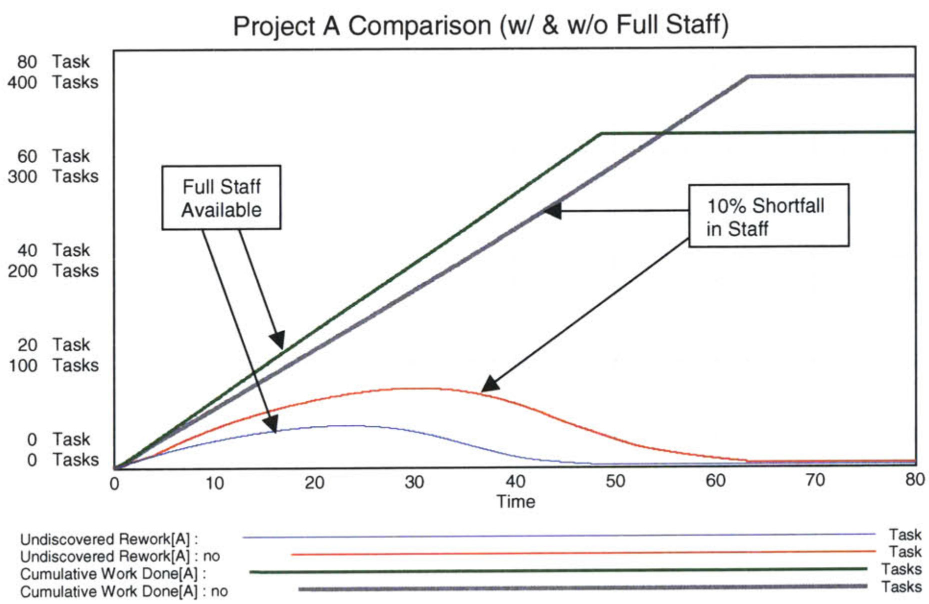
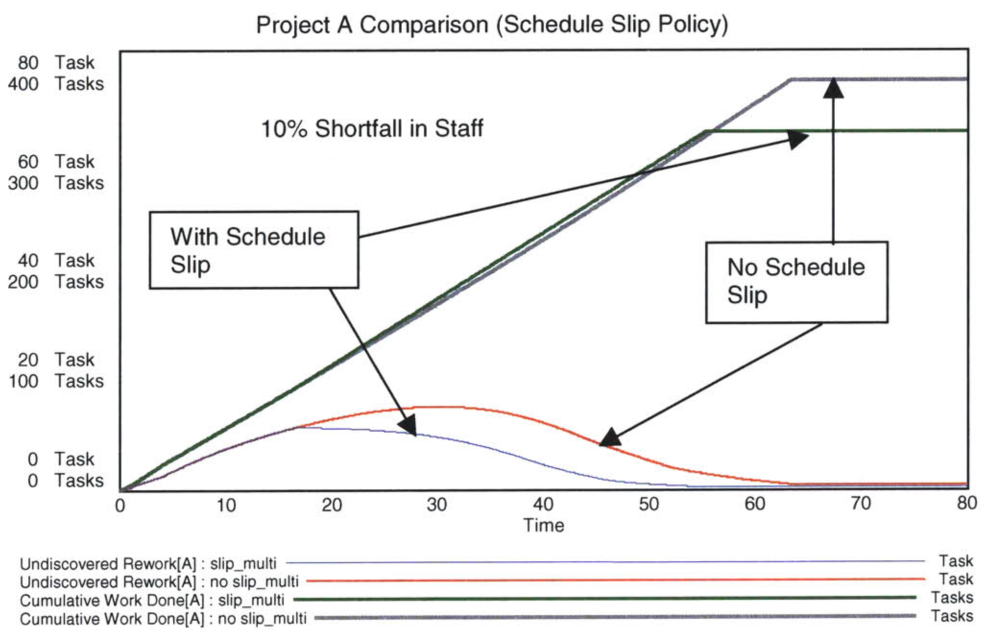


Figure 20. Comparison of Work Performed with and without Sufficient Staffing

While this scenario may be an extreme condition for a multiple project scenario, it does provide insight into the effects of a situation where the organization has intentionally staffed below resource forecasts yet projects were won and started as planned. Furthermore, it may provide additional insight to managers concerning the potential consequences of staffing projects late or below planned levels. As the analysis indicates here, trying to execute to original project schedules when resources are not available to do the work result in an increase in both cost and schedule for the projects.

Given the impact of trying to achieve original project schedules when full resource levels are unavailable, I examine a management policy, which allows for a schedule slip early in the project. To do this, the model allows for the project management to slip the scheduled completion date for the project if after 30% of the work has been completed there is an expectation that the project will be late. This policy gives managers time to assess the progress being made and to make an educated decision on whether or not to slip the project.

This management strategy was tested using the same multi-project scenario except that each project was allowed to slip schedule based on estimated completion dates. The results of such a strategy is shown in Figure 21 and are quite remarkable and counterintuitive.



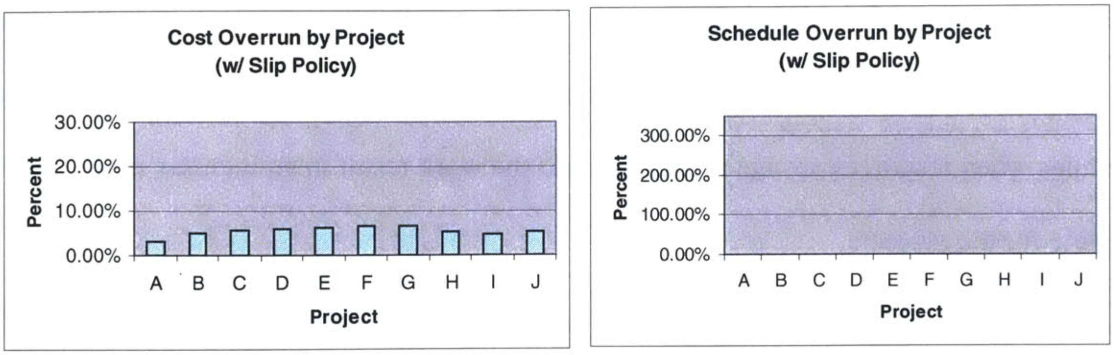


Figure 21. Comparison of "Slip" vs. "No Slip" Schedule Policy

By allowing for a schedule slip, all the projects in the pipeline finish substantially earlier than if the projects tried to achieve their original schedule. I call this a *"faster-slower"* effect. By trying to achieve the original schedule, which is faster than assigned resources will allow, the project actually completes more slowly and at a much higher cost than if a schedule slip is recognized.

For example, project "A" will finish 8 months earlier (55.5 months vs. 63.5 months) by allowing a schedule slip rather than trying to meet the original schedule. Thus, project "A" will finish only 7.5 months beyond the original planned completion date rather than 15.5 months. In addition, the total cost for the projects will also decrease significantly. By allowing for schedule slips, the average cost overrun is reduced to 5.4%. The reason behind the improvements are that by slipping the schedule, the program will go "Green" and schedule pressure will be relieved thereby maintaining planned work quality and staff productivity, i.e., effectively, maximizing the work rate and minimizing the rework generated.

Of course, slipping schedule can be very difficult in practice since more than just company management has to be convinced. Ultimately, the customer has to be convinced and be willing to accept associated impact to his/her plans. While this can be difficult to accomplish and contradictory to many manager's mental models, the end result will be less painful and the customer will ultimately be more satisfied.

Scenario 2 - Effects of Unplanned Quality Issues

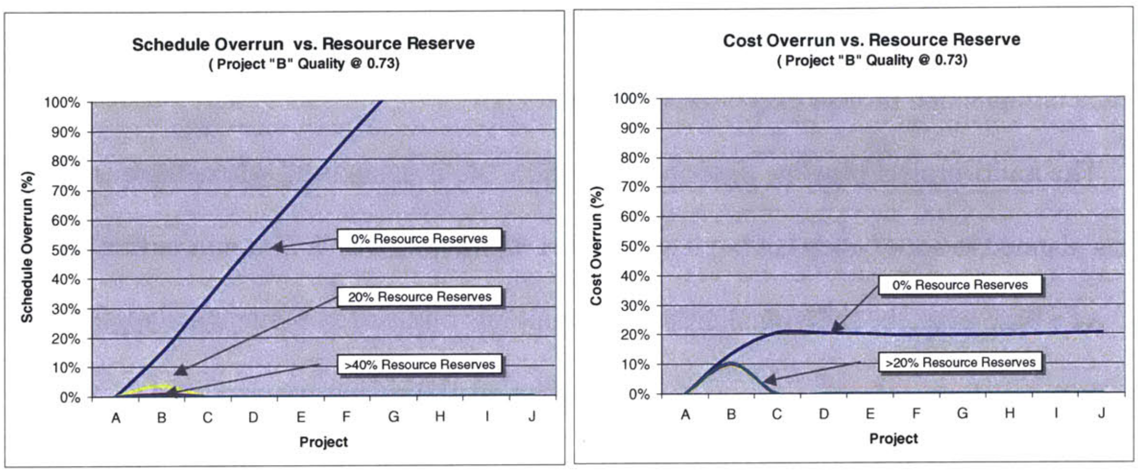
In this scenario, I examine a case of unexpected quality or rework issues within a single project and its effect on the projects following it in a project pipeline. Specifically, product development "tipping" will be evaluated. That is, I examine an organization's ability to contain and resolve execution "fires" in one project and preventing impacts to other projects in the pipeline. For this, I will perform a set of experiments designed to understand the relationship between available or reserve resources and the ability to address and correct unexpected/unplanned project execution issues quickly.

The multi-project pipeline described in Figure 18a is again used where there is 10 projects planned in series each having a duration of 48 months with a 2-month buffer between them. As a base case, the individual project assumptions outlined in Table 3 are applied to show the product development organization behavior when all 10 projects are executed as planned and with the necessary staff being available. I then compare these results to several model runs where project "B", the second project in the pipeline, experiences unexpected quality issues arising from the use of immature technology and a high level of project complexity. These runs were performed with various available staff levels. A minimum level of 80 persons up to a maximum level of 160 persons was used to simulate a "bench" of reserve resources ranging from 0% to 100% of the planned staff levels. The results of these runs are shown in Figure 22[30].

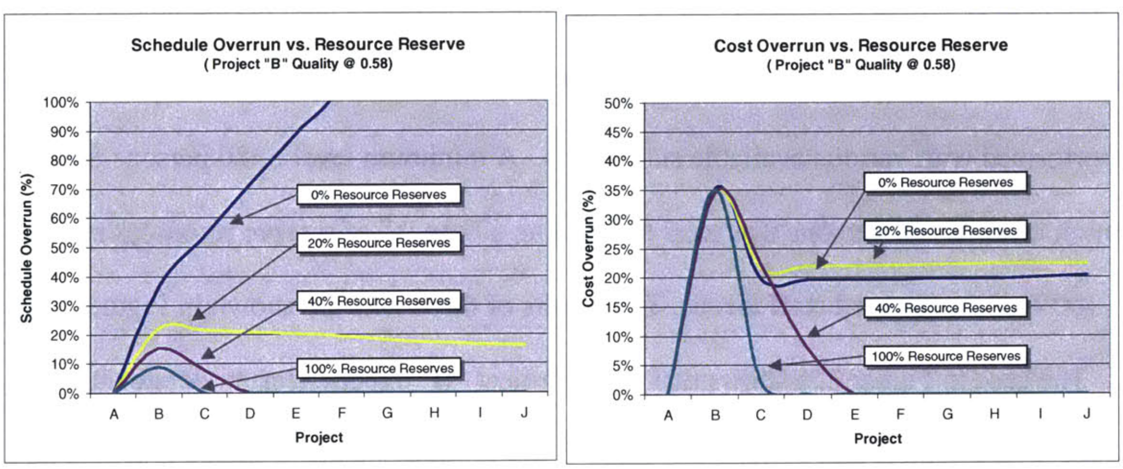
The case in Figure 22a shows that when Project "B" experiences moderate quality issues above the level planned, and there are no reserve resources available to put onto the project, the pipeline will "tip" causing each successive project to suffer continual cost and schedule overruns

[30] A complete listing of the project model (*aerospace multi_project.mdl*) and associated command files (*multiproject resource level experiments.cmd*) used to run these simulations are included in Appendix A.

even though the follow-on projects do not experience any quality issues associated with technology maturity and complexity. The "tipping" is caused because the follow-on projects are being resource starved causing them to effectively start late. If the resource reserves are greater than 20%, then the organization has the capacity to apply extra resources sufficient to prevent tipping and put out the fire without having it spread to other projects in the pipeline, i.e., Project "C", Project "D", etc. do not experience cost or schedule overruns.



a) Project "B" Quality @ 0.73, Other Project Quality @ 0.9



b) Project "B" Quality @ 0.58, Other Project Quality @ 0.9

Figure 22. Simulation Results for a Single Project that Experiences Higher Than Planned Rework (Lower Technical Maturity and Higher Complexity

In the case presented in Figure 22b where the quality issues on Project "B" are more significant, the tipping effects are quite dramatic. Again, the project pipeline will "tip" if there are no reserve resources available to respond to project issues however significantly larger resource reserves are required to contain the Project "B" issues and prevent cost and schedule overruns then from spreading to other projects. One can see that a 20% resource reserve will prevent schedule overruns from increasing but the recovery will take a very large time period while cost overruns appear near constant and will take even longer to mitigate. A 40% resource reserve will also eventually put out the fire but will not prevent the next projects from being impacted. Here, one can see that the schedule overruns are limited to projects "B" and "C" but the cost overruns will exist through Project "D". This extra delay in resolving cost overruns is due to the fact that even though the schedule issues are resolved by Project "D", Project "D" was still starved needed resources at the front-end of the project and consequently forced the project to bring on extra staff to complete on schedule. Finally, if 100% resource reserves, 2X the planned staff level, were available then the project "B" issues could be resolved before impacting cost or schedule for any other projects downstream.

These simulations suggest that pipeline 'tipping" could exist in an aerospace product/system development pipeline and that the relationship between the project plans and the available resources within the organization is possibly more important than conventional project management thinking suggests.

While it is impractical to suggest that an organization maintain twice the required staff level, half of which are residing in a "fire house" waiting for the project alarm to sound, this analysis makes it even more apparent that it is crucial that project bids and associated plans be consistent with project objectives. Furthermore, the need for reserve resources is apparent should unexpected issues arise (and they often do in product development). Thus, one can conclude that contingency planning for both project execution issues as well as reserve resources are important for effective project pipeline execution.

Scenario 3 - Simulation of Concurrent Project Pipeline

A concurrent project pipeline was simulated to verify that the observations made using the series project pipelines, in scenario 1 and 2, are applicable to pipelines having multiple concurrent projects. The concurrent project pipeline described in Figure 17b was implemented in a simulation having 13 projects: 2-platform, 2-derivative, and 9-follow-on. Each project was planned using the assumptions outline in table 3 along with a 1-month schedule buffer applied between projects.

The required or planned project staff needs for this scenario is shown in Figure 23. One can see that the planned staff level varies over time based upon the types and quantity of projects on-going at any one time. In this scenario, four cases are simulated each one assuming a fixed available staff level of 220, 240, 260, and 280 persons respectively. This provides an evaluation of positive and negative staff margins. In addition, I assume that the platform project, P1, experiences lower quality performance than planned. Here again, the lower quality level is due to the use of immature technology and a high level of project complexity. Therefore, the scenario will examine the effects of these various levels of available staff, i.e., resource reserves or a staff "bench" and its effect on project performance within the pipeline.

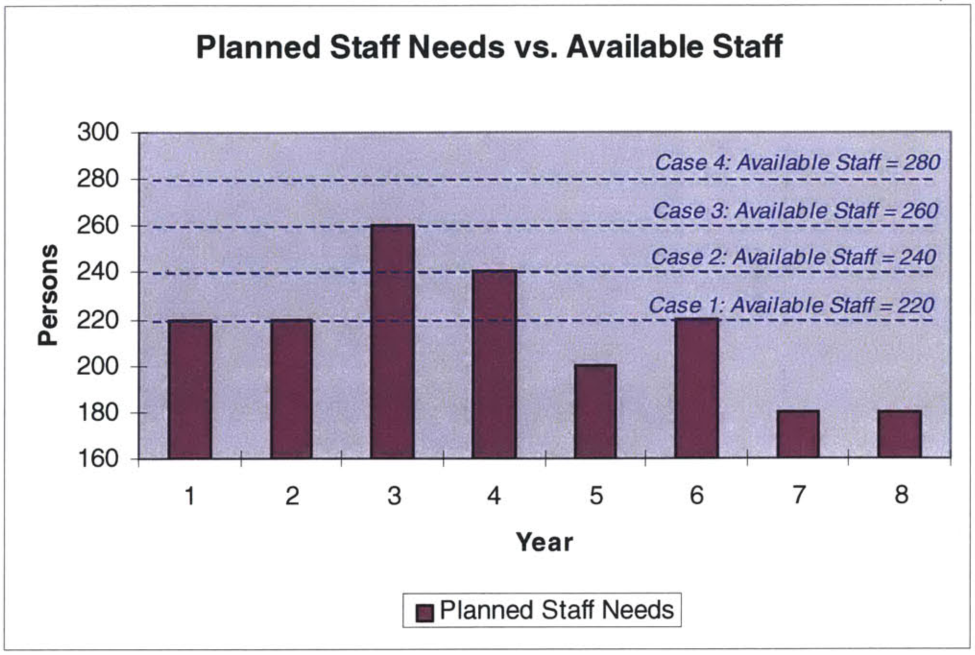


Figure 23. Planned Resource Needs for the Concurrent Multi-Project Pipeline

The simulation results are shown in Figure 24. The graphs show that project P1 exhibits a cost overrun due to the excess rework generated over that planned. Project P1 also exhibits a schedule overrun due to the late discovery of rework and the limitation in available resources to respond to the unexpected rework. Beyond the expected impacts to project P1, one can look to see if issues spread to other projects downstream. The first evidence of this is apparent for project F5 and F6, which immediately follow, project P1 in time even with excess available resources at a level of 280 persons. It is also apparent that projects D1, F1, F2, and P2 are initially unaffected due to the fact that these projects are well underway when project P1 discovers its problems. However, as the available staffing is decreased, the cost and schedule issues spread to both upstream and downstream projects about F5 and F6.

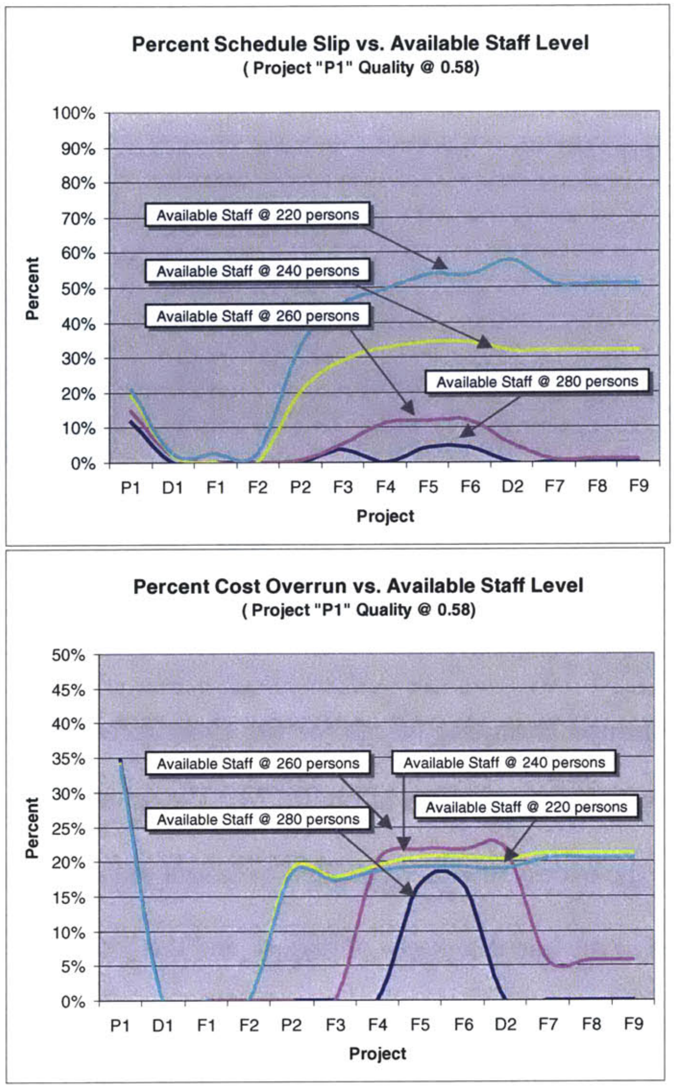


Figure 24. Cost and Schedule Performance for Scenario 3

These results also support the conclusion that it is critical to ensure that project plans are consistent with the risk level of the project and that the organization make provisions for sufficient resource reserves else the organization runs the risk of having substantial issues with the causal project and also with other projects in the pipeline.

It is the relationship between project plans along with available resources that is fundamental in establishing and assessing the project execution capacity of the organization. The cases presented here show that if project plans and resources are misaligned thereby causing a condition of the organization operating beyond its capacity to execute, poor project performance is not necessarily contained to a single project but can also impact other projects in the pipeline.

There are several pieces of information discovered in the field research that support the likelihood of a misalignment between true work scope and resources:

- Poor project bids and planning as well as staffing issues were cited as major reasons why projects got into trouble.
- The organization plans staff levels based on resource plans from currently active projects and potential future projects
  - If project plans are under estimated either from poor planning or aggressive business pursuits, the resource needs will effectively be below "true" needs
- There is considerable delay in reconciling project needs with functional staffing plans.
  - This delay impacts responding to resource needs
- The organization plans staff ~8% below forecasted levels to protect against the downside risk of not winning projects.
  - The aggregate staffing plan favors a resource constrained system.
- The company's self-assessment collected feedback regarding issues with having the "Right People at the Right Place at the Right Time".
  - The assessment highlights tension in skill supply and demand.

It would appear that this phenomenon may be one reason why the aerospace organization researched continues to experience a near 20% average level of projects that are in trouble and a near 7% average COPQ over the last 3 years.

6.2 Single Project Dynamics – Allocating the Right Resources

In this section, single project dynamics are explored to develop insight into the importance of assigning the right people to the right project. As mentioned in Section 4.2, several managers feel that the organization continues to have issues getting the right staff allocated to the right project at the right time. Managers highlighted that often times it is critical skills either in application domain experience, technology experience, or product development experience that are in short supply and sought after by many projects. This is particularly true for projects which experience execution issues and can't afford the "learning curve" delay and cost associated with less experienced staff.

One of the observations from the field research is that the organization's workforce planning system treats resources as homogeneous within a particular discipline, e.g., systems engineering, electrical engineering, etc. Yet, there are individuals within these functional groups who are often sought after because of their unique skills and capabilities. The planning and allocation of these resources to which are referred to as "critical skills" are managed less formally. This less formal management of critical skills could be susceptible to sub-optimal allocation across the organization. For example, critical skills tend to stay with a business area or project long after an initial assignment is complete due to business area pursuits for additional business or the capture of follow-on contracts which benefit from the experience of the critical skills. In another example, critical skills may tend to be allocated to the project whose manager has the "sharpest elbows" and makes the best case for why a particular resource is needed for his/her project. Furthermore, projects may have been estimated assuming the assignment of key critical resources across the organization yet there is no formal mechanism for tracking such assumptions. The danger here is that work productivity and quality assumptions are highly coupled to the staff that is assigned. This is particularly true for the organization studied as most projects highly leverage technology and past project experience. Therefore, if the right resources are not assigned to the project from the beginning, there can be significant execution issues that result.

A qualitative analysis of a single project model is explored with the intent of improving manager's mental model of the important relationships between resource skills, work quality, worker productivity, and overall project execution performance. For this, I will simulate staffing scenarios for a platform project to test the implications of various staffing decisions for the project. The outline for this section is as follows:

- Project Overview
- Key Assumptions
- Scenario 4: Effects of Matching Project Plans and Critical Skills

Project Overview

The project model consists of a single platform project, which is planned to be performed over a 48-month period. The model structure[31] is very similar to that used in the multi-project model except that additional detail has been added to account for the use of two different resource types: experienced staff and general staff. For the simulations presented here, the amount of available resources will not be limited but rather the mix of experienced and inexperienced staff will be varied to understand the associated impacts on project execution.

Key Assumptions

Project Plan, Schedule, and Time to Discover Rework: The assumptions for the project plan, schedule, and time to discover rework are consistent with that outlined in the multi-project discussion in Section 6.2

Staffing for Single Project Scenarios: As in the multi-project models, the project will continually monitor work progress and determine if additional staff is required to be brought onto the project or released from the project. Staff will be assigned at the project start and will

[31] A complete listing of the project model (*single project.mdl*) and the associated command files (*single project.cmd*) used to run the simulations are included in Appendix B.

be initialized to the planned staffing level required to complete the project on time and on schedule.

Staff will be assigned from two resource pools, one for experienced staff and one for general staff. The basic stock and flow structure is shown in Figure 25. The diagram illustrates that the *General Staff* will gain experience over a period, *Time to Gain Experience*, where they will become *Experienced Staff*. Here, I assume that all staff will eventually become experienced after 36 months and will be considered a critical skill for the organization.

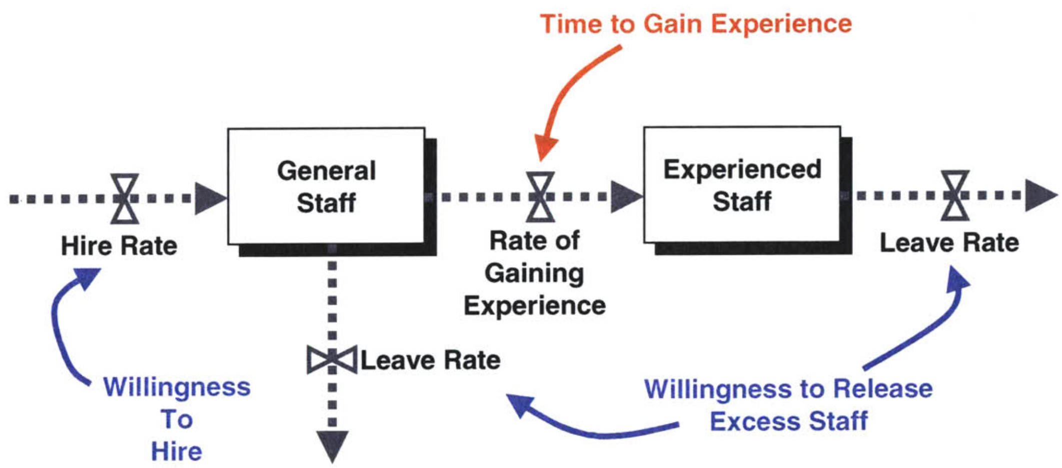


Figure 25. Basic Stock and Flow Structure for Single Project Staff

If additional staff is required beyond initial levels, then new general staff may be hired if the organization decides to do so. If excess staff exists on the project, they will be released if project management is willing to release them and only will do so when the project is well underway. The actual release will be based on the fraction of work perceived to be complete to avoid releasing staff too early in the project. In addition, if staff personnel are to be released, the general staff will be transferred first to maintain the pool of experienced staff on the project.

Productivity and Quality vs. Resource Skill Mix: The model tracks the percentage of general and experienced staff within the workforce and computes a weighted average worker productivity and work quality level. The core assumption here is that general staff, initially, have 50% of the productivity and quality of an experienced worker. As general staff gain experience with the system application and technology over the time to gain experience period, the productivity and quality become equal to that of an experienced staff member.

Quality Level and Technology Maturity, Project Complexity, and Process: As discussed in Section 6.1, the model computes an effective quality level over time based upon several inputs generated within the model: schedule pressure, project "Red" pressure, quality on quality, requirements uncertainty, technology maturity, project complexity, process maturity/rigor, and skill mix. For each of these parameters, a value is either defined or computed by the project dynamics. These values are then factored with the normal productivity level estimated for the project. For example, the effective quality level for a case of the normal quality equal to 0.9, technology maturity equal to 0.9, and complexity factor equal to 0.9 would be equal to 0.9^3 or 0.73.

In these scenarios, the technology maturity, project complexity, and process development factors will be varied to emulate rework effects caused by inexperience or immaturity with a particular technology, defects created by complexity within a project, and quality issues that result from an overly tailored development process.

Scenario 4 - Effects of Matching Project Plans with Critical Resource Needs

In this scenario, the effects of matching project plans and staff mix is examined. The purpose here is to explore a hypothetical case where a project was optimistically planned by assuming high normal quality levels and productivity levels commensurate with an assumption of high technology maturity, process capability, and the availability of key critical/experienced staff for project execution but, in reality, a lesser experienced staff was put on the project. The motivation for such a study was feedback from the organization wanting to understand the relationship between critical skills and project performance that improve the resource decision-making process.

Such a scenario is plausible in those instances where a particular project is highly challenged from a technical performance, cost, and schedule standpoint. In the organization's effort to win such a project, the proposal and plan are based on historical performance and assumptions on the type of staff that will be available to execute the work. While this example case does not explicitly look at any particular project, it is believed to provide some meaningful insight into how staff experience drives quality and productivity performance of a project. A recommended area of future work is to calibrate a project model based on actual project data from typical projects within the subject organization to understand the implications of staffing and other project execution factors. Such a case was reported by Lyneis[32] for automotive development where staffing was reportedly identified as the second highest contributor to project execution risk.

First, I look at a simple case of a project, which was planned to be executed by a full staff of experienced staff members. This is then compared to a 75%/25%, 50%/50%, and 25%/75% mix of experienced staff to general staff to understand the performance implications. For this first case, the project was assumed to have a normal quality and productivity level of 0.9 with technology maturity, complexity factor, and process development factor all equal to 1, however, a sensitivity factor recognizing quality on quality issues was applied to reflect the reality that additional work is created when downstream work is based on incorrect upstream work. In addition, it is assumed that the project management will not release any staff until the project is finished. The results are shown in Figures 26, 27, and 28.

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[32] James Lyneis, "Dynamics of Project Performance", Class 7, ESD.36j – System and Project Management, MIT, Fall 2002.

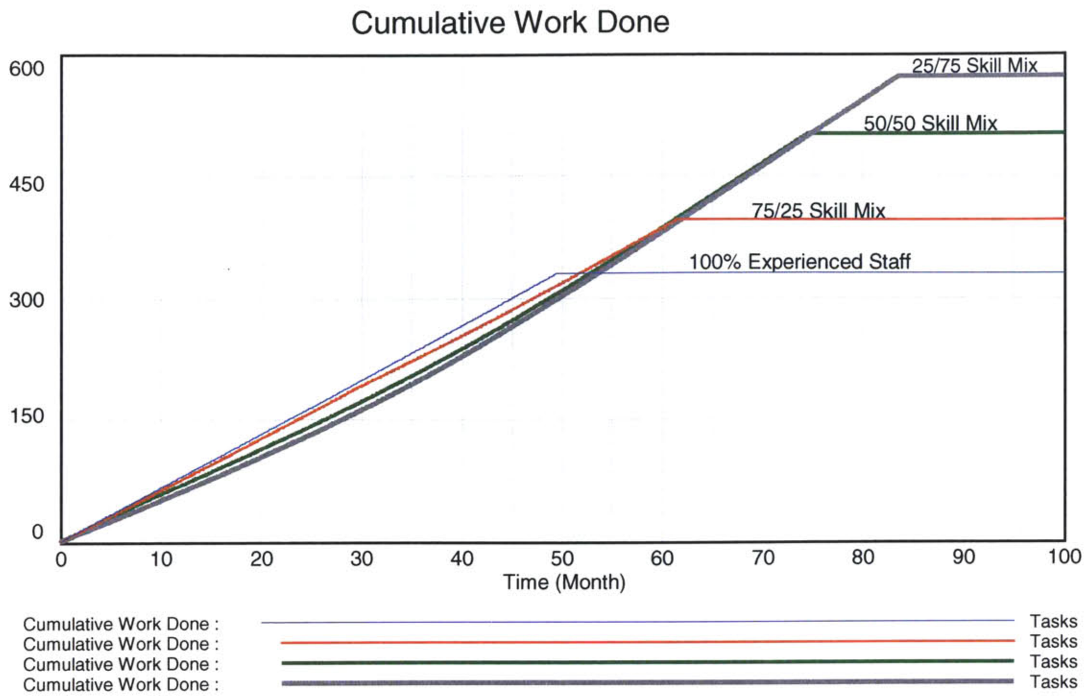

Figure 26. Impact of Resource Mix on Total Work Performed

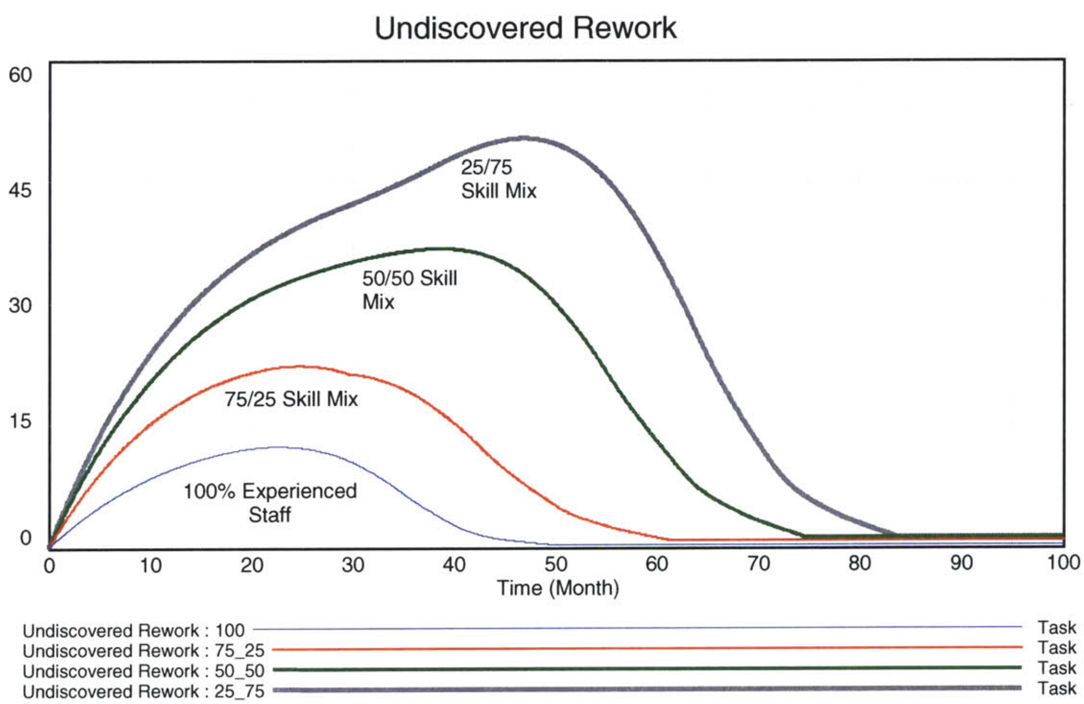

Figure 27. Impact of Resource Mix on Rework Generation

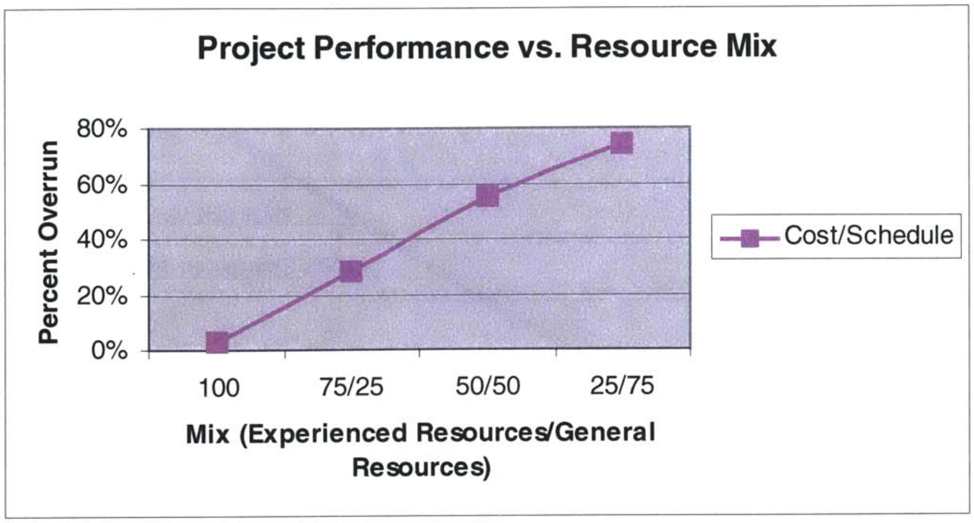

Figure 28. Impact of Resource Mix on Cost and Schedule Performance

The results show that as the mix of experienced resources decreases, the amount of rework or total work performed increases thereby extending the schedule and increasing the cost of the project by a substantial amount. The fundamental factor behind this behavior is the higher rework that is generated by the lesser-experienced staff. First, the rework itself is undetected for an extended period of time due to the time required to discover the rework. This effectively can provide managers a false sense of satisfaction in the near term since the work appears to be progressing adequately. However, when the rework begins to be discovered it quickly becomes apparent that there are a number of defects and ultimately more work has to be performed to complete the project.

Perhaps more importantly, because defects can be caused by several factors that drive the effective quality and are not discovered until late in the project, the causes for the defects can be subjective and are difficult to attribute to skill mix. Often defects are blamed on many factors and it is difficult to pin point the specific causes. This is no surprise since work quality and ultimately defects are dependent on several factors that are not easily isolated. In fact, while managers at the organization felt the skill mix issues were present on many projects, there was a lack of tangible data directly supporting such claims. It is hoped that this analysis may provide some additional insight in the understanding of the effects and magnitude that can result from skill mix issues and that it is critical that the right skills be matched to the project assumptions and needs.

The next part of the scenario was focused on understanding the best staffing policies when projects go "Red". In particular, should more experienced staff be allocated to resolve issues? What are the implications of adding more general staff?, should the staff remain constant and simply continue to work through the issues?, or should the staff remain constant and the cost/schedule be slipped?

For this, a simulation was performed assuming that the project experienced additional quality issues related to technology maturity, project complexity, and development process tailoring over the level planned for the project. I further assume that the project will be initially staffed with experienced staff members. During the simulation, managers will be allowed to hire and release staff during the course of the project. Within the simulation, there are four cases that will be evaluated:

1. "Plan" – a baseline simulation of the project which will include the original project plan assumptions of an initial experienced staff of 80, a normal quality and productivity equal to 0.9, and no technology, complexity, or process quality issues, i.e., all equal to 1.
2. "Const Staff" – a simulation of project performance assuming 80 experienced staff members are assigned with no hiring allowed. In addition, I assume that there will be quality issues associated with the technology maturity, complexity factor, and process factor equal to 0.9 respectively.

3. "Const Staff_Slip"- a simulation of project performance given the quality issues described in case 2 but the project will be allowed to slip schedule. In addition, it is assumed that the project will recognize cost growth as necessary due to the quality issues that will relieve pressures associated with the project being "Red".
4. "Hire GenStaff" – a simulation of project performance given the quality issues described in case 2 but hiring will be allowed to increase the staff level up to 160 persons only after the project goes "Red". In addition, the initial staff will be 70 experienced staff members thereby reflecting a management challenge to execute the project with approximately 12% less staff than originally planned.
5. "Hire ExpStaff" – this simulation is identical to case 4 except that only experienced staff will be hired and assigned to the project.

The simulation results are shown in Figures 29, 30, 31, and 32.

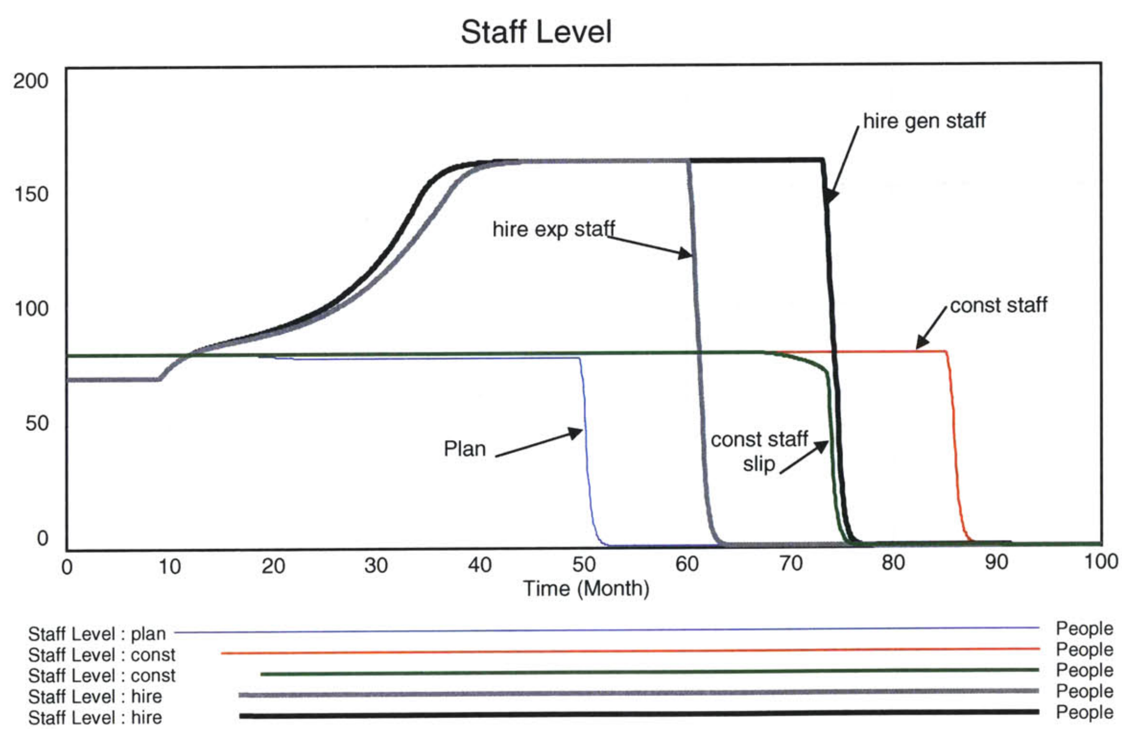

Figure 29. Staffing Profiles for Scenario 4

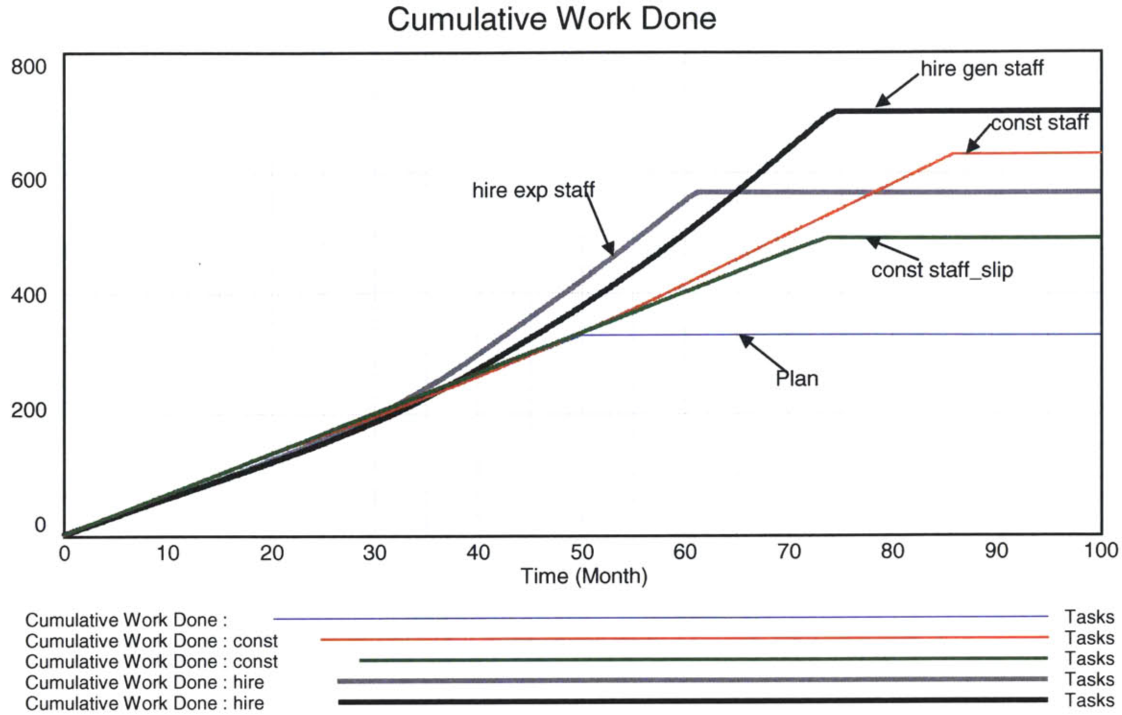

Figure 30. Total Work Performed for Scenario 4.

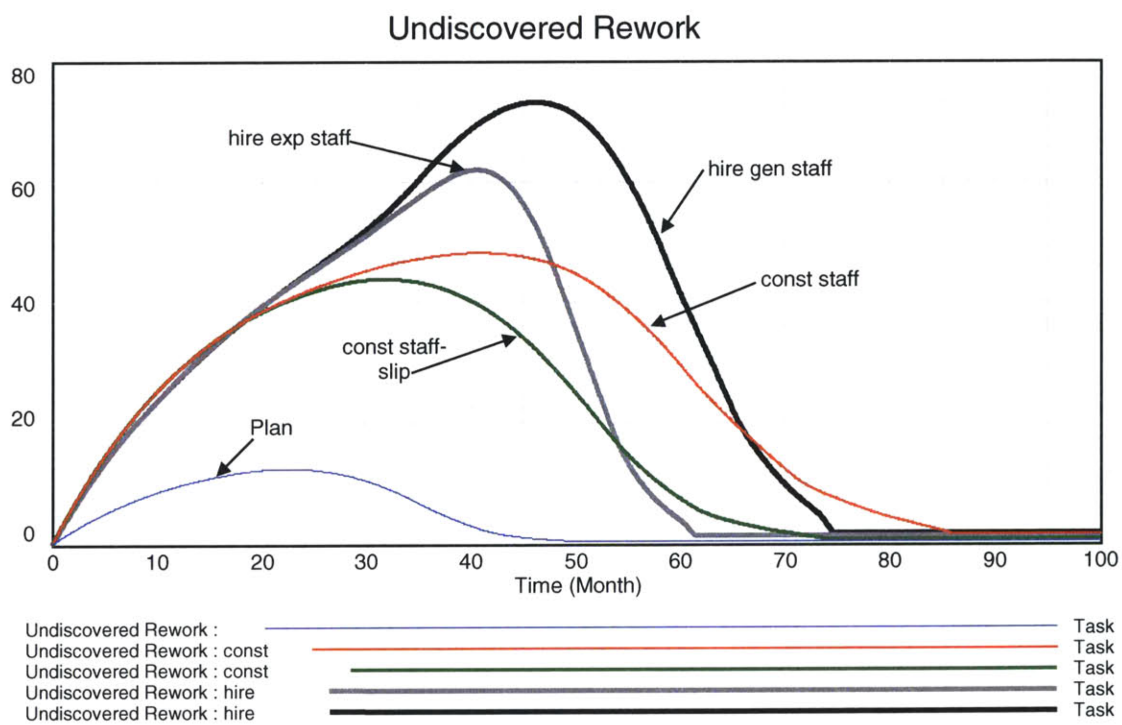

Figure 31. Rework Generation for Scenario 4

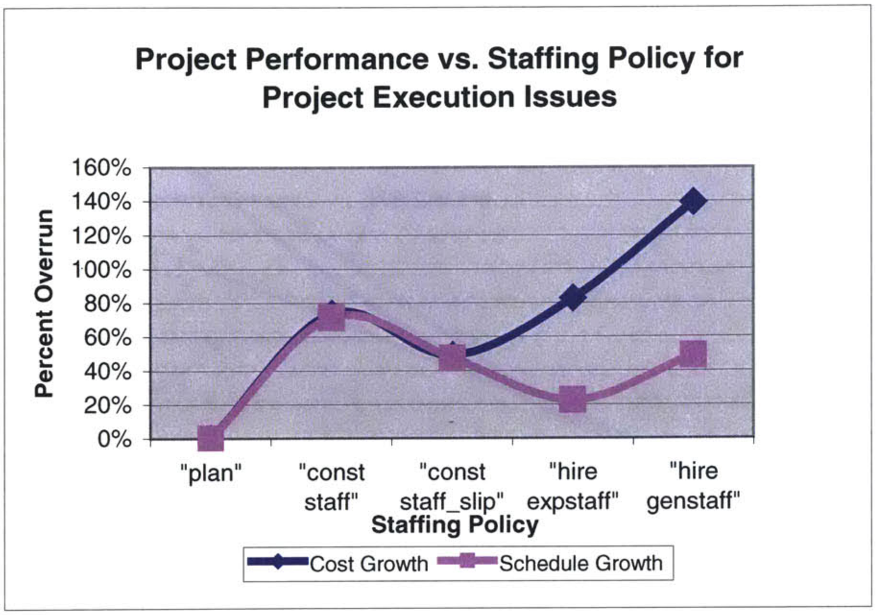

Figure 32. Cost and Schedule Performance for Scenario 4

The simulation results show that when a project experiences quality issues, more work will have to be performed than originally planned. Ultimately, this will result in cost growth for the project unless work scope or product features can be eliminated. The question then is "how to best deal with the execution issues?" One can see that in all cases, "const staff", "const staff_slip", "hire expstaff", and "hire genstaff", there are substantial cost and schedule implications for the quality issues not planned into the project. Of all the staffing choices available in dealing with the individual project issues, there are only two options that are worth considering; either maintaining the existing experienced staff and slipping/restructuring the project or hiring experienced staff. The latter option will result in the best schedule performance but only at a considerable cost growth over the planned expenditures. In effect, adding experience staff serves to increase the net project team productivity while maintaining good work quality in spite of the persistent schedule and management pressure quality effects. However, this option is less likely in practice since experienced staff is hard to come by. The former option, maintaining the existing staff and slipping the project, yields the best compromise between cost and schedule impact. As articulated in the multi-project analysis, recognizing project issues early and slipping the project schedule along with recognizing necessary cost increases results in a more efficient project execution as this serves to eliminate quality impacts associated with trying to achieve an unachievable schedule. In fact, this option will result in cost and schedule performance that is much better than trying to execute the project with the original staff and to the original plan or trying to add additional staff, which is not experienced. Maintaining the original staff without a project slip once again results in slower project execution in spite of efforts to execute faster. This is due to the fact that by trying to achieve the original schedule with a condition of substantial unplanned rework, there is considerable schedule pressure applied to the staff that continues to impact the work quality in spite of attempts to increase productivity. In the case of hiring more general, less experienced staff, the schedule growth is mitigated over keeping the existing staff but cost growth increases considerably over the other options. This is because as more general staff are added, the aggregate quality and productivity of the project team is decreased, thereby creating more rework and extending the project schedule and cost position. Another observation is that the results seem to defy Brook's Law[33]. The simulation presented here shows that adding manpower does not necessarily make the project later principally because staff is added early in the project due to the project going "Red" and the recognition of rework mid-way through the project. If the rework was discovered much later, the results would not be so favorable for adding general staff and there would be an increased need to add only experienced staff to the project.

While the simulation presents only a hypothetical scenario, the results do show the significance of two key findings for projects which experience unexpected quality issues: 1)

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[33] Frederick P. Brooks, Jr., "Adding manpower to a late software project makes it later." The Mythical Man-Month. Reading, MA, Addison Wesley, 1995.

slipping the project schedule and recognizing the associated cost growth early in the project will result in faster project completion and lower total project costs than trying to execute to the original project plan, and 2) schedule performance can only be optimized by adding experienced staff provided additional cost growth can be tolerated. These findings suggest that to improve project execution performance across the organization, project managers need to recognize project execution issues early in the project and act quickly to negotiate necessary project budget and schedule changes. Furthermore, while the value of experienced staff may resonate with most managers, perhaps this more strongly emphasizes the need for the development of a broader base of critical skills within the organization particularly if projects are aggressively proposed and subject to quality issues associated with the use of advanced technologies, high levels of complexity, and process tailoring.

6.3 Strategies for Improving Project Performance

Important strategies for improving project performance are derived from a holistic view of the dynamics associated with business objectives, project bids/proposals, project plans, availability of critical resources, and the productivity and quality factors that influence the rework cycle. Fundamentally, a desire to grow business by winning projects and increasing customer satisfaction is defeated in the long run when projects are under planned or under estimated. While near-term results may be attractive, in the long run, projects will inevitably suffer overruns leading to customer dissatisfaction and loss of new or follow-on business. Furthermore, poorly planned projects will cause resource plans to be understated thus limiting the entire organizations ability to staff projects and address project fires which inevitably arise in product/system development. Therefore, the most important factor in improving the organization's capacity to successfully execute projects is to improve project bids, proposals, and project plans so that they are consistent with the true work scope of the project and the available resources within the organization.

While the author is not so naive to suggest that project execution issues and "Red"/"Yellow" projects can be eliminated in total, field data along with the analyses discussed suggest that there are two specific strategies or management "levers" for improving the organization's ability to execute product/system development projects.

Slipping projects earlier rather than later by recognizing execution issues early in a product/system development effort leads to faster, lower cost project execution: The analysis suggests that trying to achieve an unachievable schedule only leads more significant increases in cost and schedule. The impacts to decisions to "press on" despite management indicators of major cost and schedule risk ultimately create additional work within the project since work quality decreases, design defects increase, often leading to disastrous results.

By recognizing work scope and work quality that is inconsistent with project plans, allocated resources, budgets, and schedule targets early in a project, the organization can avoid the pitfalls of trying to achieve an unachievable plan and avoid further cost and schedule growth. In fact, the analysis shows that projects that recognize slips early will actually finish faster and at a lower cost than projects, which do not recognize execution issues. This strategy is counterintuitive since slowing of the project pace actually results in faster project execution.

Not only do these decisions affect the project itself, but it can also affect other projects in the pipeline since resources will often be pulled or stolen from other projects to fight fires thereby causing other projects to be impacted. The multi-project analysis demonstrates that projects that depend on common resources are coupled since the execution performance of one project can affect another. Thus, if one project is late, it will use and maintain resources longer and will tend to starve downstream projects of necessary personnel thereby adding delays and pressure to the next project. As such, early recognition of individual project slips will not only improve performance of the principal project but can also improve the performance of the overall project pipeline.

Provision for resource reserves beyond planned project levels to respond to and contain project execution issues: Whether resource reserves are included as part of the project plan or as part of the organization's aggregate resource plan, provisioning for reserve resources can have dramatic effects in responding to project issues, putting out fires, and preventing them from spreading to other projects in the pipeline. Such a policy inherently recognizes the variability associated with product/system development. In manufacturing systems, where there is arguably less variability due to the inherent repetition of manufacturing work tasks, utilization or capacity is carefully considered to prevent and often kept below 80% to protect against excessive queues. Why then should a development organization plan their resources at a 90% utilization when the work is much more variable? Furthermore, history suggests that EMD projects, particularly, those using new technology or new applications often experience unexpected resource demands. Such a historical view of the project pipeline development variability or risk could provide a means for "top down planning" of such reserves.

Furthermore, reserve pools of experienced staff are highly desirable and effective at mitigating project impacts. As such, there is a large incentive to carefully plan the allocation of existing experienced staff members as well as in the development of additional staff with similar critical experience and skills.

Chapter 7

Summary and Recommendations for Future Work

This research has explored the project performance of the product development system of one aerospace enterprise in an attempt to understand the relationship between project execution capacity and resource planning in an aerospace context. A fundamental premise in the research is that the level of fire fighting is an indicator of the organization's capacity to effectively execute projects to planned cost, schedule, and performance targets, i.e., the higher the level of fire fighting in projects the higher the utilization of the organization's capacity to execute projects effectively.

The project performance of the enterprise over the last eight years has been studied to find that while considerable progress has been made in reducing the level of project fire fighting, almost 20% of all on-going projects continue to be in trouble at any given time. Of this 20%, most of the troubled projects are EMD efforts where almost 1/3 of all EMD projects experience "Red" or "Yellow" conditions at sometime in their development life cycle. In addition, the cost of poor quality (CoPQ) has averaged 7% of the total annual sales over the last 3 years. While this past year, CoPQ was less than 1%, it is unclear whether this trend will continue or if it is a temporary condition.

It is observed that when projects get into trouble, they are in trouble for a considerable period of time. On average, the duration of "Red" or "Yellow" conditions lasts for an average of 8.5 months with a standard deviation of 10.2 months. The research also indicates that most troubled projects cannot recover without some level of customer relief, either in cost, schedule, or performance.

Efforts to empirically derive the project execution capacity of the organization did not yield an apparent correlation between the number or type of projects in the pipeline to the number of troubled projects. Rather, observations here served to support the hypothesis that the development capacity of the organization is largely determined by the consistency between project bids & plans and the true work scope within projects along with the level of available resources. Additional support for this hypothesis is provided from field data collected concerning the central causes of project fire fighting identified by the organization. The six central causes cited were: poor bid & proposals, poor planning and execution, staffing, poor supply chain management, process, and poor requirements/integration & test management. Here, the first three categories contribute directly to project execution capacity considerations outlined. That is, the balance between product development resources and the product development work load itself.

Two system dynamics models were developed to explore the relationship between resource planning and product development performance in both a multi-project and a single project context. These models were constructed for an aerospace product development framework to maximize the relevancy to real world conditions. The multi-project analysis demonstrates that project pipeline *"tipping"* is a possible condition for aerospace organizations due to aggressive resource planning behaviors and policies. As such, adverse project execution effects are shown to spread from the causal project to other projects within the pipeline thereby causing self-reinforcing execution issues for many projects across the organization. The single project analysis explored the importance of allocation the right resources to a project. Here, the dependence of project performance on work productivity and quality is shown to have considerable implications to the success of a project.

Using these models, strategies were established to provide managers with effective policies for addressing project execution issues for both individual projects and the multi-project pipeline itself. Here, two management levers are identified to improve project performance when execution issues arise: slip projects which experience execution issues early in their life-cycle and provision for resource reserves to respond to unplanned development work.

First, slipping projects earlier rather than later by recognizing execution issues early in a product/system development effort leads to faster, lower cost project execution. A *"faster-slower"* phenomenon is experienced when projects try to achieve original project plans by attempting to complete work faster than the allocated resources will allow. Such a management policy of trying to achieve the original plan can induce negative quality effects that result in ultimately generating more work to do before the project can finish thereby degrading cost and schedule performance. This also serves to understate the aggregate resource demands across the organization and leads to over utilization of staff personnel.

Second, provisioning for resource reserves allows the organization to respond to project issues and contain the fire fighting within the project pipeline. Unless work scope can be eliminated in troubled projects or projects are allowed to slip, the availability of reserve resources are key to resolving execution issues associated with unplanned project work and also preventing the spread of fire fighting to other projects.

Finally, there two areas that are suggested as future work for this research. First, it is believed that this analysis can benefit from the development of a project model "calibrated" to projects within the organization. In this research, a simplified, single-phase model was used to qualitatively explore the project performance behaviors to various product development system conditions. By having a project model that was calibrated to actual projects, perhaps deeper insight can be gained for improving and refining management policies. Second, it is also believed that an analysis of the long-term business dynamics associated with project execution performance be investigated by gaining a deeper understanding of the relationship between aggregate project performance and long-term business growth.

Appendix A

Multi-Project System Dynamics Model

Text File – Aerospace Multi-Project.mdl

```
********************************************************
	.aerospace multi-project.mdl		A. McQuarrie
********************************************************~
		Project Model
	|

project : A,B,C,D,E,F,G,H,I,J
	~
	~	projects A,B,C, etc.
	|

ACWP[project] = Cumulative Effort Expended[project]
	~	Month*Person
	~	Represents the actual cost for work performed. The ACWP is the actual \
		effort expended to complete the work believed to be done. ACWP is a \
		fundamental measure used in EVM (earned value management)
	|

Aggregate Customer Satisfaction Level=
	IF THEN ELSE(SUM(Project Finished[project!])>0, SMOOTHI ( Instantaneous Cumulative
Customer Satisfaction\
		, 50, 100) ,0)
	~	Dimensionless
	~		|

Anticipated Schedule Overrun[project] = ( ( Perceived Real Completion Date[project] -\
		 Scheduled Completion Date[project] ) / Scheduled Completion Date[project] ) * Project
Finished\
		[project]
	~	Fraction
	~	The fraction by which the current estimate of completion date exceeds the \
		scheduled completion date.
	|

Available Staff = INTEG( ( Total Release Rate + Hire Rate - Total Assignment Rate - "Transfer/Layoff
Rate"\
		 ) , Initial Staff )
	~	persons
	~	This is the total staff available for assignment to projects. The \
		available staff is determined by hiring, release of staff from projects, \
		assignment of staff to projects, and transfers or layoffs.
	|

Average Productivity[project]=
	IF THEN ELSE ( Cumulative Effort Expended[project] > 1, Work Believed to Be Done[project\
```

] / Cumulative Effort Expended[project] , Productivity[project])
~ Task/(Month*Person)
~ Average productivity to date on the project simply equals work believed to \
be done divided by cumulative effort (person-months) spent to date. Note \
that this measure equates to productivity as defined in the model, and is \
not adjusted for quality.
|

Average Work Quality[project] = Max (1e-006, Work Done[project]) / Max (1e-006, Work Believed to Be Done\
[project])
~ Fraction
~ The average quality of all the "upstream" work done to date. This equals \
work done (correctly) divided by total work done (which includes \
undiscovered rework).
|

BCWP[project] = (Total Budgeted Cost[project]) * Fraction Perceived to be Complete[\
project]
~ Month*Person
~ Represents the budgeted cost for work performed. The BCWP is the \
planned/budgeted effort required to complete the fraction of work \
perceived to be complete. BCWP is a fundamental measure used in EVM \
(earned value management)
|

BCWS[project]=
MIN ((Time - Planned Start[project])* Project Start[project] *(Total Budgeted Cost\
[project]) / (Planned Duration[project]+(Planned Duration[project]-Initial Planned Duration\
[project])), Total Budgeted Cost[project])
~ Month*Person
~ Represents the budgeted cost for work scheduled. The BCWS is the planned \
effort required to complete the work planned to be done. BCWS is a \
fundamental measure used in EVM (earned value management). Note, the BCWS \
profile will be updated each time there is a schedule slip. This will \
allow for the accumulated schedule variance to be eliminated and the \
program will go "green".
|

Budgeted Cost to Complete[project] = (Initial Cost Estimate[project] + Rework Cost Estimate\
[project]) * (1 - Fraction Perceived to be Complete[project])
~ Month*Person
~ The budget estimate used in the model takes initial work to do, adds the \
estimated amount of rework expected on the project, and divides this by \
normal productivity to determine person-months required to execute the \
project. As fraction perceived complete increases, the "budget-based" \
amount of work remaining decreases.
|

Change in Schedule[project] = Max (0, Schedule Slip[project]) / Time to Slip Schedule
~ Months/Month
~ This is the rate at which the schedule will change
|

Changes[project] = Work Done[project] * (STEP (Fraction Changed[project] / TIME STEP\
, Time of Change[project]) - STEP (Fraction Changed[project] / TIME STEP , Time of Change\
[project] + TIME STEP))
~ Tasks/Month
~ |

Completion Off Switch[project] = IF THEN ELSE (Project Completion Date[project] > 1,\
0, 1)
~ Dimensionless
~ This "switch" is used to identify when a project completion date has been \
determined. It is used with the Completion On Switch to create a momentary \
"on" condition for the project completion switch which in turn is used to \
turn on the recognition of completion flow for one time step.
|

Completion On Switch[project] = 1 - Project Finished[project]
~ Dimensionless
~ Creates a value of 1 when the project is completed.
|

Complexity Factor = 1
~ Dimensionless
~ The complexity factor is used to capture the quality effects attributed to \
the complexity of a project. For example, a project with many associate \
contractors or external interfaces can introduce added complexity which \
can result in rework due to misunderstood requirements, interface changes, \
etc. The rework or quality level of complex projects is typically higher \
than on projects with lower complexity.
|

Cost Weighted Customer Satisfaction[project] = (Customer Satisfaction[project] * Total Budgeted Cost\
[project] + 1e-006) / (SUM (Total Budgeted Cost[project!]) + 1e-006)
~ Dimensionless
~ For each project, the customer satisfaction level will be scaled by the \
total budgeted cost of the project. Therefore, more costly projects will \
carry more weight when calculating the overall customer satisfaction level \
for the organization.
|

CPI[project] = IF THEN ELSE (Time - Planned Start[project] > 4, Project Finished[project\
] * ((BCWP[project] + 1e-005) / (ACWP[project] + 1e-005)) , 1 * Project Start[project\
] * Project Finished[project])
~ Fraction
~ CPI is the cost performance index. It is the ratio of BCWP to ACWP. A \
value greater than 1 indicates favorable cost performance (below plan) and \
a value less than 1 indicates unfavorable cost performance (ahead of \
plan). Note, CPI is forced to "1" for the first 4 months of the planned \
schedule duration. It is assumed that it take 4 months to staff the \
project, develop a project plan, and baseline it for earned value \
measurement.
|

Cumulative Effort Expended[project] = INTEG(Effort Expended[project] , 0)
~ Month*Person
~ |

Cumulative Work Done[project] = INTEG(Rate of Doing Work[project] , 0)
~ Tasks
~ Keeps track of how many total tasks have been done or redone on the \
project. Includes original work and rework.
|

Customer Satisfaction[project] = MIN (100 * CPI[project] * SPI[project] , 100)
~ Dimensionless
~ Customer satisfaction is estimated and quantified to be equal to the cost \
performance index (CPI) multiplied by the schedule performance index (SPI) \
for the project which is then normalized over a scale of 100. Both CPI and \
SPI can range from 0 to >1. Therefore, if both cost and schedule targets \
are met, the customer satisfaction will equal 100. Note, that when a \
project completes, SPI goes to 1 by definition but CPI does not. \
Therefore, when project are completed, customer satisfaction will \
naturally increase but the level will be limited by the CPI attained at \
project completion.
|

Development Process Factor[project] = 1
~ Dimensionless
~ Development Process Offset is used to offset the normal quality level. A \
low offset value reflects a mature and rigorous product development \
process where as a higher value is reflective of an organization whose \
process is less mature and/or has been highly tailored (relaxed) to meet \
aggressive schedule demands.
|

Effect of Prior Work Quality on Quality[project] = Sensitivity for Effect of Quality on Quality\
* Table for Effect of Prior Work Quality on Quality (Average Work Quality[project\
]) + (1 - Sensitivity for Effect of Quality on Quality)
~ Dimensionless
~ This effect represents the fact that undiscovered errors in upstream work \
products tend to cause errors in current work. The effect is specified in \
the table relationship driven by average work quality to date, and can be \
reduced or increased by the sensitivity multiple.
|

Effect of Schedule Pressure on Productivity[project] = Table for Effect of Schedule Pressure on PDY\
(Anticipated Schedule Overrun[project]) * Sensitivity for Effect of Schedule Pressure on
Productivity\
+ (1 - Sensitivity for Effect of Schedule Pressure on Productivity)
~ Dimensionless
~ Schedule pressure, based on the fraction by which the current estimate of \
completion date exceeds the original completion date, causes productivity \
to increase. That is, people are assumed to work faster, and perhaps \
longer hours as overtime is not included in this model, the greater the \
anticipated schedule overrun.
|

Effect of Schedule Pressure on Quality[project] = Sensitivity for Effect of Schedule Pressure on Quality\
* Table for Effect of Schedule Pressure on Quality (Anticipated Schedule Overrun[\
project]) + (1 - Sensitivity for Effect of Schedule Pressure on Quality)
~ Dimensionless
~ Schedule pressure, based on the fraction by which the current estimate of \
completion date exceeds the original completion date, causes quality to \

decrease. That is, while people are assumed to work faster, and perhaps \
longer hours as overtime is not included in this model, the greater the \
anticipated schedule overrun (see effect on productivity), they also make \
more mistakes in a "haste makes waste" effect. Also, overtime fatigue may \
cause additional errors.

|

Effect of Work Progress[project] = Table for Effect of Work Progress (Fraction Really Complete\
[project])

~ Dimensionless

~ Drives the time to discover rework from its maximum value to the minimum \
value as fraction really complete increases from 0 to 1.

|

Effort Expended[project] = Staff Level[project] * Project Finished[project]

~ People

~ |

Estimated Cost to Complete[project] = (Budgeted Cost to Complete[project] * (1 - "Weight on Progress-Based Estimates"\
[project]) + (Estimated Cost to Complete Based on Progress[project]) * "Weight on Progress-Based Estimates"\
[project]) * Project Finished[project]

~ Month*Person

~ Estimated cost to complete, in person-months, depends on the budgeted cost \
to complete and the estimated cost to complete based on progress. Early in \
the project before management can perceive actual productivity and \
quality, the tendency is to believe the budget. As progress is made, the \
weight on the progress-based estimate increases until that estimate \
replaces the budget cost estimate.

|

Estimated Cost to Complete Based on Progress[project] = Work to Do[project] / Average Productivity\
[project]

~ Month*Person

~ Estimated cost to finish the project, in person-months, is found by \
dividing work to do by average productivity. Note that this cost estimate \
does not adjust for any estimates of undiscovered rework, or for any \
trends in productivity or quality problems.

|

Estimated Rework[project]=
32

~ Tasks

~ This value represents the estimated rework required on the project \
measured in tasks. In this case, the estimated rework is 10% of the tasks \
planned.

|

Feasible Work Rate[project] = MIN (Maximum Work Rate[project] , Potential Work Rate[\
project])

~ Tasks/Month

~ |

Fraction Changed[project] = 0

~ Fraction

~ Used to represent a percent of rework required based on an internally or \
externally driven requirements change.

|

Fraction Complete to Finish = 0.99

~ Fraction

~ |

Fraction of Available Resources[project] = (Project Priority[project] + 1e-005) / (\
SUM (Project Priority[project!]) + 1e-005)

~ Dimensionless

~ This parameter represents the fraction of the available resources to be \
assigned to a project when there is an insufficient supply of available \
staff to support the various project demands. It is computed as the ratio \
of the project priority over the sum of all project priorities. It \
represents a management policy that supports spreading scarce resources \
across projects relative to their project priority level. Note, the \
resource allocation policy is to only assign available resources. On-going \
projects who have staff already assigned will not be reallocated until the \
project releases them.

|

Fraction Perceived to be Complete[project] = Work Believed to Be Done[project] / (Initial Work to Do\
[project] + 1e-006)

~ Fraction

~ The fraction of work management believes is done correctly. This fraction \
includes undiscovered rework as well as work actually done correctly.

|

Fraction Really Complete[project] = Work Done[project] / (Initial Work to Do[project\
] + 1e-006)

~ Fraction

~ The fraction of work that is really complete in contrast to the fraction \
believed to be complete. The fraction really complete only includes work \
done, and not undiscovered rework.

|

Hire Rate = IF THEN ELSE (Total Staffing Margin >= -2, 0, (Total Staffing Margin / \
Hiring Delay) * Willingness to Hire)

~ persons/Month

~ The hire rate represents the rate at which new staff will be hired or \
transferred in from outside the organization. Note that the rate is scaled \
by the managements willingness to hire.

|

Hiring Delay = 6

~ Month

~ Reflects the average time required to perceive and/or act on the need for \
new staff and obtain them internally, or from outside the organization. \
This is longer than the transfer-firing delay, because locating people \
outside can be time consuming, and internal transfer may be slow because \
of needs on other projects. Furthermore, the delay may be a result of \
uncertainty in the true staffing needs thus resulting in management \
waiting to make sure the needs are real before obtaining more staff.

|

Imputed Cost of Schedule Overrun[project] = Schedule Overrun[project] * Imputed Cost Per Month of Overrun\
[project]
~ Month*Person
~ |

Imputed Cost Per Month of Overrun[project] = 0
~ Person
~ |

Indicated Completion Date Based on Progress[project]=
IF THEN ELSE (Time - Planned Start[project] > 1, Time + (Estimated Cost to Complete\
[project] / Max (10, Staff Level[project])) , Initial Scheduled Completion[project\
])
~ Month
~ Indicated completion date takes the current project time and adds to that \
the time required to finish the estimated work remaining assuming no \
change in staff (i.e., estimated cost to complete divided by current \
staff).
|

Initial Cost Estimate[project] = Initial Work to Do[project] / Normal Productivity[project\
]
~ Month*Person
~ |

Initial Planned Duration[project]=
48
~ Months
~ This represents the initial duration for the project before any decision \
to slip is made.
|

Initial Scheduled Completion[project] = Planned Start[project] + Planned Duration[project\
]
~ Month
~ This is the initial estimated or required schedule for when the project is \
to be completed. The value represented here is the month when the project \
is planned/targeted to be finished and is equal to the planned start date \
plus the planned duration.
|

Initial Staff=
80
~ persons
~ |

Initial Work to Do[project]=
288
~ Tasks
~ The initial scope of the project.
|

Instantaneous Cumulative Customer Satisfaction = SUM (Cost Weighted Customer Satisfaction\
[project!])
~ Dimensionless

~ This is the aggregate customer satisfaction level for the organization. It \
reflects the customer satisfaction level with the organization as a \
product/systems developer and will factor into follow-on contracts and new \
business.

|

Maximum Staff Level[project]=
IF THEN ELSE (Willingness to Increase Max Staff[project] = 1, 160, 100)
~ persons
~ Imposes a maximum staff level to be assigned to a project. The level is \
dependent on a willingness to increase maximum staff above some level \
determined by the project management team. Note, the ETC will be \
continually used to determine the staff level required to complete. A \
limit on the staff level requested is made to avoid impractical resource \
requests and to limit the staffing requests based on the project \
management policy.

|

Maximum Time to Discover Rework = 18
~ Months
~ The time to discover rework early in the project when strictly design \
tasks are being done.

|

Maximum Transfer Rate = 10
~ persons/Month
~ This represents the maximum rate at which staff can be transferred or laid \
off.

|

Maximum Work Rate[project] = Work to Do[project] / Minimum Time to Finish a Task
~ Tasks/Month
~ |

Minimum Time to Discover Rework[project] = 0.25
~ Months
~ The time to discover rework late in the project when building and testing \
tasks are being done.

|

Minimum Time to Finish a Task = 0.125
~ Months
~ The average minimum time it takes to execute a task.

|

Minimum Time to Finish Work = 1
~ Month
~ For planning staffing, the minimum time over which management desires to \
complete the remaining tasks. Note that this is larger than the minimum \
time required to finish any one task.

|

Normal Productivity[project] = 0.08333
~ Task/(Month*Person)
~ The represents the normal productivity level expected on average

|

Normal Quality[project] = 0.9
~ Fraction
~ This represents the normal quality level experienced on an average project
|

Perceived Real Completion Date[project]=
SMOOTHI (MIN(Scheduled Completion Date[project]+1*Initial Planned Duration[project]\
, Indicated Completion Date Based on Progress[project]) , 0.1*Time to Perceive Real Schedule\
[project] , Scheduled Completion Date[project])
~ Month
~ Perceived completion date lags indicated completion date. This lag \
reflects delays in management's perception of the real status of the \
project, or reluctance to act on that status.
|

Percent Cost Overrun[project] = 100 * (Total Project Cost[project] - (Initial Cost Estimate\
[project] + Rework Cost Estimate[project]) + 1e-006) / (Initial Cost Estimate[project\
] + Rework Cost Estimate[project] + 1e-006)
~ Fraction
~ Used to compute the percentage of cost overrun for a given project.
|

Percent Schedule Overrun[project] = (Schedule Overrun[project] / Planned Duration[project\
]) * 100
~ Fraction
~ Used to compute the percentage of schedule overrun.
|

Planned Duration[project]= ACTIVE INITIAL (
Scheduled Completion Date[project] - Planned Start[project],
Initial Planned Duration[project])
~ Months
~ This represents the planned duration that the project is \
required/estimated to take to complete. The planned duration may change \
depending on the willingness to slip.
|

Planned Start[project]=
0, 50, 100, 150, 200, 250, 300, 350, 400, 450
~ Month
~ This represents the planned start dates for all the projects in the \
pipeline. The planned month is the month that the project is planned to \
start.
|

Potential Work Rate[project] = Staff Level[project] * Productivity[project] * Project Finished\
[project]
~ Tasks/Month
~ The rate at which tasks could be accomplished if there is enough work to \
be done.
|

Productivity[project] = Normal Productivity[project] * Effect of Schedule Pressure on Productivity\
[project] * "Program Red?"[project]
~ Task/(Month*Person)

~ Productivity represents tasks accomplished per person-month of effort, \
whether done right or wrong. Normal productivity is the output that would \
result if the impacts of all simulated effects on productivity are 1.0; \
therefore, normal productivity represents the effects of all non-modeled \
factors on productivity.

|

"Program Red?"[project] = IF THEN ELSE ((CPI[project] < 0.9 :OR: SPI[project] < 0.9\
) :AND: Project Finished[project] * Project Start[project] = 1, 0.9, 1 * Project Finished\
[project])

~

~ A program or project is considered "Red" if the CPI or SPI is less than \
0.9. This parameter used to scale productivity and quality as a result of \
the program going "Red". Going "Red" creates additional burden and \
pressure on the staff as a result of unplanned reporting activities \
(reviews, meetings, etc) to the customer or senior management. \
Productivity will be reduced since staff will be diverted to unplanned \
activities. Quality will be reduced due to the additional pressure on the \
staff and a tendency to skip process steps and accelerate tasks.

|

Project Active[project] = Project Finished[project] * Project Start[project]

~ Dimensionless

~ Equals "1" if project is active. Equals "0" if project is not active

|

Project Assignment Rate[project] = IF THEN ELSE (Available Staff >= Total Incremental Resource Demand\
:AND: Project Incremental Resource Requirement[project] > 0 :AND: Available Staff \
> 0, Project Incremental Resource Requirement[project] / Time to Assign , IF THEN ELSE\
(Available Staff * Fraction of Available Resources[project] >= Project Incremental Resource Requirement\
[project] :AND: Project Incremental Resource Requirement[project] > 0 :AND: Available Staff\
> 0, Project Incremental Resource Requirement[project] / Time to Assign , IF THEN ELSE\
(Available Staff > 0 :AND: Project Incremental Resource Requirement[project] > 0,\
Fraction of Available Resources[project] * Available Staff / Time to Assign , 0))\
)

~ persons/Month

~ The project assignment rate is the rate at which staff are assigned to a \
given project. If the available staff exceeds total demand from all \
projects then all projects will be assigned requested staff. If the is a \
shortfall in the available staffing supply then staff will be assigned on \
a percentage basis given the fraction of available resources parameter \
determined by the project priority levels.

|

Project Completion Date[project] = INTEG(Recognition of Completion[project] , 0)

~ Month

~ This construct is used to capture the project completion date. The stock \
integrates an impulse at the time of project completion with a height of \
Time/Time Step which lasts for 1 Time Step thus yielding the project \
completion date.

|

Project Completion Switch[project] = Completion On Switch[project] * Completion Off Switch\
[project]
~ Dimensionless
~ This switch is momentarily set to 1 when the project is completed and the \
Completion On Switch is set to 1. The switch will create an impulse of 1 \
lasting 1 time step where the Completion Off Switch will go to 0 after a \
project completion date has been set.
|

Project Finished[project] = IF THEN ELSE (Work Done[project] > Fraction Complete to Finish\
* Initial Work to Do[project] , 0, 1)
~ Dimensionless
~ The project is defined to be finished when 99% of the work is done. The \
project finished switch shuts off the application and accounting of labor \
to the project.
|

Project Incremental Resource Requirement[project] = Staff Level Required to Complete[\
project] - Staff Assigned to Project[project]
~ persons
~ This represents the difference between the staff level needed and the \
staff level assigned. It is used to continually monitor project resource \
demands versus the levels currently assigned. If additional staff is \
needed, this parameter is used to determine the assignment rate of \
additional staff.
|

Project Priority[project] = Max (Project Priority Rank[project] * Project Incremental Resource Requirement\
[project] , 0)
~ Dimensionless
~ Project priority is the project priority ranking multiplied by the \
incremental resource requirement. Therefore, projects with the largest \
resource demands/shortfalls will attain higher priority in allocating \
limited staff.
|

Project Priority Rank[project]=
10
~ Dimensionless
~ This represents the priority ranking for a given project from a scale of 1 \
to 10. A score of 10 signifies the highest priority for the project. \
Priority ranking is used to determine resource allocation when staffing \
demand exceeds the supply available.
|

Project Release Rate[project] = Max (- Project Incremental Resource Requirement[project\
] / Time to Release[project] , 0)
~ persons/Month
~ This is the rate at which a project will release excess staff. The excess \
staff level exists when there is a negative incremental resource \
requirement, i.e., supply exceeds demand.
|

Project Start[project] = IF THEN ELSE (Time >= Planned Start[project] , 1, 0)
~ Dimensionless
~ This parameter is used to signify when the project has started. It will \
have a value of 1 if the planned start month has arrived and will be 0 \
otherwise. It is used to enable or "turn on" the staffing demand ("staff \
level required to complete") only when the project is scheduled to \
officially.
|

Quality[project] = Normal Quality[project] * Effect of Prior Work Quality on Quality[\
project] * Effect of Schedule Pressure on Quality[project] * "Program Red?"[project\
] * Complexity Factor * Technology Maturity Factor[project] * Development Process Factor\
[project]
~ Fraction
~ This represents the normal quality level expected on average
|

Rate of Doing Work[project] = Rework Generation[project] + Work Accomplishment[project\
]
~ Tasks/Month
~ |

Recognition of Completion[project] = Project Completion Switch[project] * (Time - Project Completion Date\
[project]) / TIME STEP
~ 1
~ This parameter creates an impulse with a height equal to the Time divided \
by a Time Step. The impulse is created or gated by the project completion \
switch.
|

Rework Cost Estimate[project] = Estimated Rework[project] / Normal Productivity[project\
]
~ Month*Person
~ Rework cost estimate (RCE) represents the budget allocation established \
for "known-unknowns". That is, it is known that there will be some rework \
required based on past program performance, however, it is unknown exactly \
which tasks will require rework. RCE is estimated to be 10% of the initial \
work to do.
|

Rework Discovery[project] = (Undiscovered Rework[project] / Time to Discover Rework[\
project]) * Project Finished[project]
~ Task/Month
~ The rate of discovering errors in prior work products.
|

Rework Generation[project] = (1 - Quality[project]) * Feasible Work Rate[project]
~ Task/Month
~ Work being done incorrectly.
|

Schedule Overrun[project] = Max (0, Project Completion Date[project] - Planned Start\
[project] - Planned Duration[project])
~ Months

~ |

Schedule Slip[project] = Willingness to Slip[project] * Max (0, (Perceived Real Completion Date\
[project] - Scheduled Completion Date[project])) * Table for Schedule Slip (Fraction Perceived to be Complete\
[project])
~ Months
~ This is the estimated schedule slip based on the perceived completion date \
and the currently schedule completion date
|

Scheduled Completion Date[project] = INTEG(Change in Schedule[project] , Initial Scheduled Completion\
[project])
~ Month
~ This is the stock that tracks the scheduled completion date for the \
projects
|

Sensitivity for Effect of Quality on Quality = 0
~ Dimensionless
~ Increases or decreases the strength of the effect of prior quality on \
current quality specified in the graphical relationship.
|

Sensitivity for Effect of Schedule Pressure on Productivity=
1
~ Dimensionless
~ Increases or decreases the strength of the effect of schedule pressure on \
current productivity specified in the graphical relationship.
|

Sensitivity for Effect of Schedule Pressure on Quality=
1
~ Dimensionless
~ Increases or decreases the strength of the effect of schedule pressure on \
current quality specified in the graphical relationship.
|

SPI[project] = IF THEN ELSE ((Time - Planned Start[project]) > 4, (BCWP[project] \
+ 1e-009) / (BCWS[project] + 1e-009) * Project Finished[project] , 1 * Project Start\
[project] * Project Finished[project])
~ Fraction
~ SPI is the schedule performance index. It is the ratio of BCWP to BCWS. A \
value greater than 1 indicates performance ahead of schedule and a value \
less than 1 indicates performance behind schedule. Note, SPI is forced to \
"1" for the first 4 months of the planned schedule duration. It is assumed \
that it take 4 months to staff the project, develop a project plan, and \
baseline it for earned value measurement.
|

Staff Assigned to Project[project] = INTEG(Project Assignment Rate[project] - Project Release Rate\
[project] , 0)
~ persons
~ This represents the amount of staff assign to a particular project.
|

Staff Level[project] = Staff Assigned to Project[project]
~ persons
~ |

Staff Level Required to Complete[project] = MIN (Estimated Cost to Complete[project]\
/ Time Remaining[project] , Maximum Staff Level[project]) * Project Finished[project\
] * Project Start[project]
~ persons
~ This parameter represents the average staff level determined to be needed \
to complete the remaining work by the scheduled completion date. It is \
estimated based on the ETC and the time remaining on the project. Note, \
that this staffing demand will be set to 0 is the project has not yet \
started by scaling the value by the project start switch.
|

Table for Effect of Prior Work Quality on Quality ([(0,0)-(1,1)],(0,0.05),(0.1,0.1),\
(0.2,0.2),(0.3,0.3),(0.4,0.4),(0.5,0.5),(0.6,0.6),(0.7,0.7),(0.8,0.8),(0.9,0.9),(1,\
1))
~ Dimensionless
~ |

Table for Effect of Schedule Pressure on PDY(
[(-0.2,0)-(1,2)],(-0.2,0.85),(-0.1,0.95),(0,1),(0.1,1.025),(0.2,1.075),(0.3,1.15),(0.4\
,1.25),(0.5,1.325),(0.6,1.375),(0.7,1.4))
~ Dimensionless
~ |

Table for Effect of Schedule Pressure on Quality ([(0,0)-(1,1)],(0,1),(0.103976,0.991228\

),(0.214067,0.951754),(0.30581,0.881579),(0.406728,0.811404),(0.5,0.758772),(0.599388\
,0.736842),(0.703364,0.732456))
~ Dimensionless
~ |

Table for Effect of Work Progress ([(0,0)-(1,1)],(0,1),(0.1,1),(0.214067,0.973684),(\
0.33945,0.916667),(0.422018,0.77193),(0.5,0.6),(0.6,0.364035),(0.678899,0.214912),(\
0.8,0.0877193),(0.896024,0.0394737),(1,0))
~ Dimensionless
~ |

Table for Schedule Slip(
[(-0.004,0)-(1,2)],(0.00214067,0),(0.0727584,0),(0.0788991,0),(0.124954,0),(0.183291\
,0),(0.293823,0),(0.3,1),(0.560942,1),(1,1))
~ Dimensionless
~ This table represents the management sensitivity for recognizing a schedule \
slip based on the perceived percent complete. In this case, management is \
highly sensitive and will recognize a full schedule slip but only after the \
fraction of work perceived to be complete reaches 30% or more.\!\!\!
|

"Table for Weight on Progress-Based Estimates" ([(0,0)-(1,1)],(0,0),(0.1,0),(0.2,0),\

(0.296636,0.00877193),(0.342508,0.0438596),(0.342508,0.0482456),(0.376147,0.0921053\

),(0.391437,0.114035),(0.434251,0.263158),(0.5,0.5),(0.556575,0.666667),(0.66055,0.890351\

),(0.727829,0.960526),(0.8,1),(0.9,1),(1,1))
~ Fraction
~ |

Technology Maturity Factor[project] = 1
~ Dimensionless
~ Technology maturity refers to the maturity and development organization \
experience with the technology applied to the project. The value defined \
here is used to offset the normal quality level.
|

Time of Change[project] = 15
~ Month
~ Represents point in time where the changes are identified
|

Time Remaining[project] = Max (Minimum Time to Finish Work , Scheduled Completion Date\
[project] - Time)
~ Month
~ The months remaining before the project reaches the scheduled completion \
date. Once that date is reached, the model assumes that management tries \
to finish the project in a minimum time.
|

Time to Assign = 0.5
~ Month
~ Imposes a delay in the time it take to assign staff. This delay is \
believed to consistent the time necessary to coordinate, transfer, and \
integrate the staff into a project.
|

Time to Discover Rework[project] = Maximum Time to Discover Rework * Effect of Work Progress\
[project] + (1 - Effect of Work Progress[project]) * Minimum Time to Discover Rework\
[project]
~ Month
~ The average time between when an error is created and when it is \
discovered. This average is assumed to start at a maximum value early in \
the project, and then fall to a minimum value as the fraction of the \
project completed increases. Because this model represents the entire \
project, we assume that early activities create the design, which is then \
later coded and tested (if software) or built (if hardware). Therefore, \
errors are most readily discovered when the project is in the code/test or \
build phases.
|

Time to Perceive Real Schedule[project] = 1 + (1 - Project Finished[project]) * 1e+006
~ Month
~ During the project, the effective time constant is 1 month; after project \
finishes, the time constant is set to a large number such that the \
equations recognize the project completion date has occurred.
|

Time to Release[project] = Max (6 * Project Finished[project] , 0.5)
~ Month
~ Time to release represents the average time it takes to release a person \
from a project. Note, that when a project is on-going it takes longer to \

release them than it does when a project is completes. This is due to the \
fact that managers are reluctant to release staff until they are sure \
that there work is completed and/or transferred and that there are no \
other tasks that need their attention.

|

Time to Slip Schedule = 1

~ Months

~ This is the time it takes management to decided if and how much to slip \
the schedule of a project

|

Total Assignment Rate = SUM (Project Assignment Rate[project!])

~ persons/Month

~ This represents the aggregate rate at which staff are being assign to \
projects.

|

Total Budgeted Cost[project] = (Initial Cost Estimate[project] + Rework Cost Estimate\
[project]) * Project Finished[project] * Project Start[project]

~ Month*Person

~ This represents the total budgeted cost for the project.

|

Total Incremental Resource Demand = SUM (Project Incremental Resource Requirement[project\
!])

~ persons

~ This is the aggregate incremental resource demand for all the on-going \
projects. The incremental resource demand is the difference between the \
assigned staff and the staff level needed to complete the project to the \
planned schedule. This is used to determine the project assignment rate. \
which will depend on whether adequate staff is available for all projects \
or if a partial allocation needs to be made based on project priority and \
staffing needs.

|

Total Project Cost[project] = Cumulative Effort Expended[project] + Imputed Cost of Schedule Overrun\
[project]

~ Month*Person

~ |

Total Release Rate = SUM (Project Release Rate[project!])

~ persons/Month

~ Represents the aggregate release rate of staff from projects back to the \
available staff pool for re-assignment to other projects. Note, staff are \
not released for re-assignment unless the project management decides to \
release them.

|

Total Staff Assigned = SUM (Staff Assigned to Project[project!])

~ persons

~ This is the aggregate staffing level assigned to all on-going projects.

|

Total Staffing Margin = Available Staff + SUM (Staff Assigned to Project[project!])\
- SUM (Staff Level Required to Complete[project!])

~ persons
~ This is the instantaneous staffing margin that exists within the \
organization. It is the comparison between staffing demand and staffing \
supply. A negative value means that a staffing shortfall exists and a \
positive value means that there is excess staff available.
|

"Transfer-Layoff Delay" = 1
~ Month
~ It is assumed that only one month is required to lay off or transfer \
workers outside the organization.
|

"Transfer/Layoff Rate" = (Maximum Transfer Rate / "Transfer-Layoff Delay") * "Willingness to Transfer-Layoff"
~ persons/Month
~ This represents the rate at which staff is being transferred or laid off \
from the organization.
|

Undiscovered Rework[project] = INTEG(Rework Generation[project] - Rework Discovery[project\
] + Changes[project] , 0)
~ Task
~ Work which contains errors and will need to be redone, but the need for \
which has not yet been recognized.
|

"Weight on Progress-Based Estimates"[project] = "Table for Weight on Progress-Based Estimates"\
(Fraction Perceived to be Complete[project])
~ Fraction
~ Management is assumed to switch from a budget-based estimate of effort \
remaining to the progress-based estimate as fraction perceived complete \
increases. The weight on progress-based estimates is also used to prevent \
layoffs early in the project, when failure to consider rework and \
productivity/quality problems might otherwise indicate an excess of staff.
|

Willingness to Fire[project] = 1
~ Dimensionless
~ |

Willingness to Hire = 0
~ Dimensionless
~ Represents management's willingness to hire or transfer additional staff \
into the organization. Note, this value can range anywhere from 0 to 1. 0 \
means no hiring, and 1 means hiring as indicated to get the work done in \
the time remaining per the current schedule.
|

Willingness to Increase Max Staff[project] = 0
~ Dimensionless
~ This parameter is set to "1" if an increase in the maximum staff level \
will be allowed/authorized by the project. A value of "0" is indicative of \
a policy that staff shall not be assigned greater than a predetermined \
maximum level.
|

Willingness to Slip[project]=
1
~ Dimensionless
~ A fraction between 0 and 1: 0 means no schedule slip allowed, and 1 means \
slipping the schedule as required.
|

"Willingness to Transfer-Layoff" = 0
~ Fraction
~ This is the willingness to fire or transfer staff. This can be a number \
between 0 and 1. 1 means that management is very willing to transfer staff \
if project needs do not exist
|

Work Accomplishment[project] = Quality[project] * Feasible Work Rate[project]
~ Task/Month
~ Work being done correctly.
|

Work Believed to Be Done[project] = Undiscovered Rework[project] + Work Done[project]
~ Tasks
~ Work believed by management to be done at any time includes work actually \
done correctly plus undiscovered rework.
|

Work Done[project] = INTEG(Work Accomplishment[project] - Changes[project] , 0)
~ Task
~ Work done correctly.
|

Work to Do[project] = INTEG(Rework Discovery[project] - Rework Generation[project] -\
Work Accomplishment[project] , Initial Work to Do[project])
~ Task
~ Work to do on the project includes the initial scope, plus tasks which \
include errors as these errors are discovered.
|

****
.Control
**~
Simulation Control Parameters
|

FINAL TIME = 700
~ Month
~ The final time for the simulation.
|

INITIAL TIME = 0
~ Month
~ The initial time for the simulation.
|

SAVEPER =
TIME STEP

~ Month
~ The frequency with which output is stored.
|

TIME STEP = 0.125
~ Month
~ The time step for the simulation.
|

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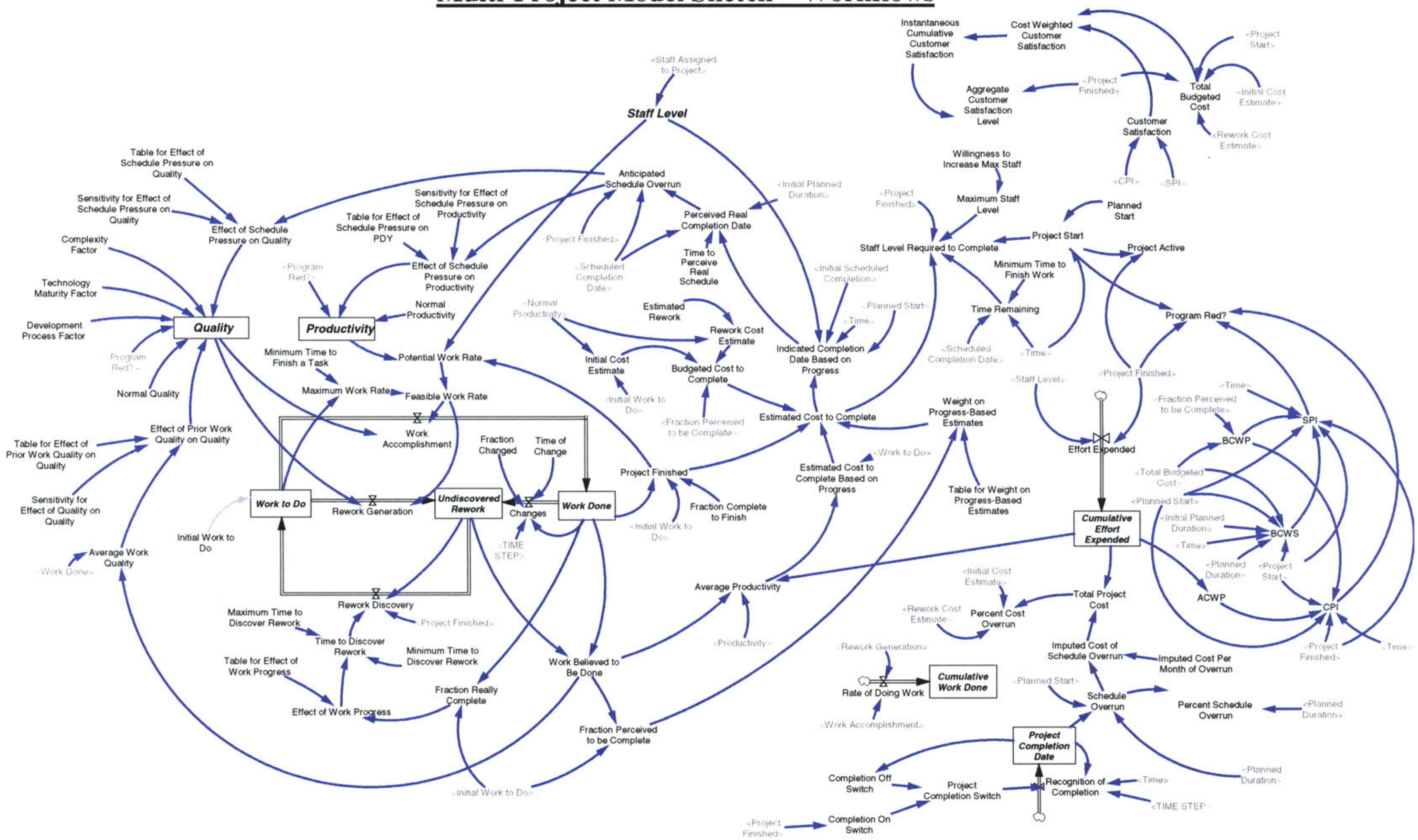
Multi-Project Model Sketch – Workflows



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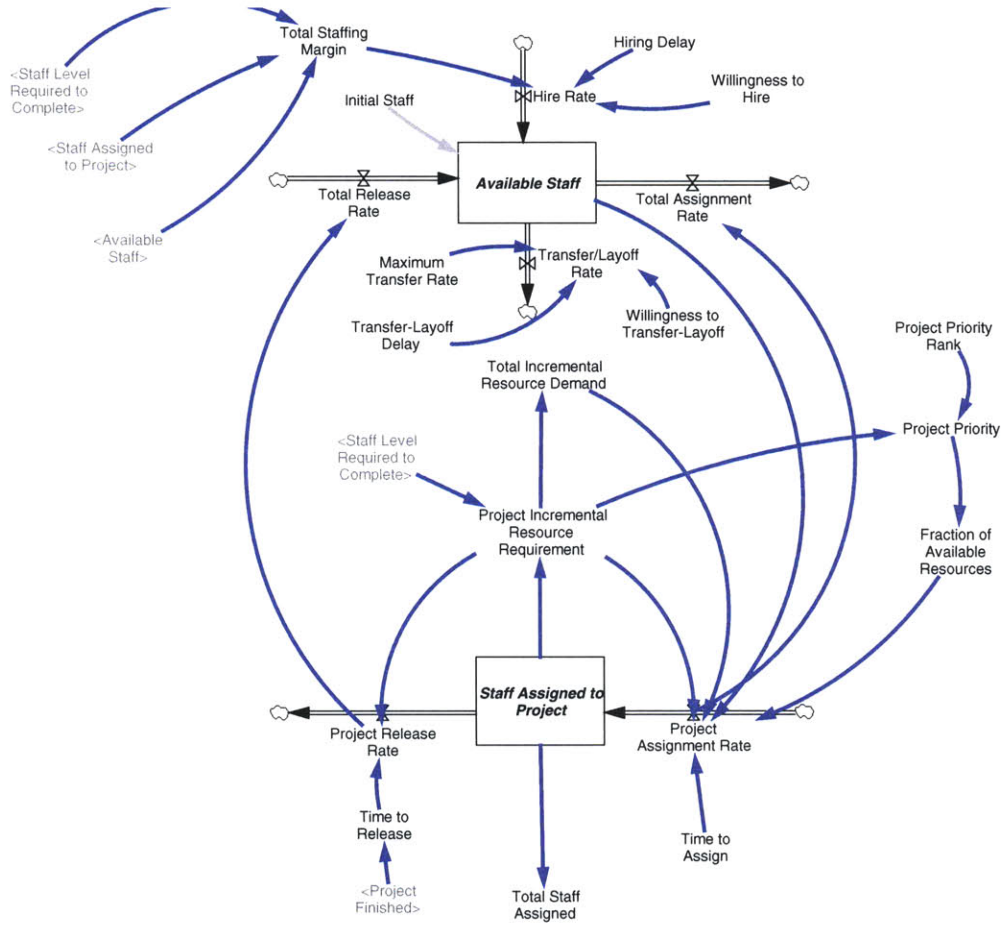
Multi-Project Model Sketch – Staffing



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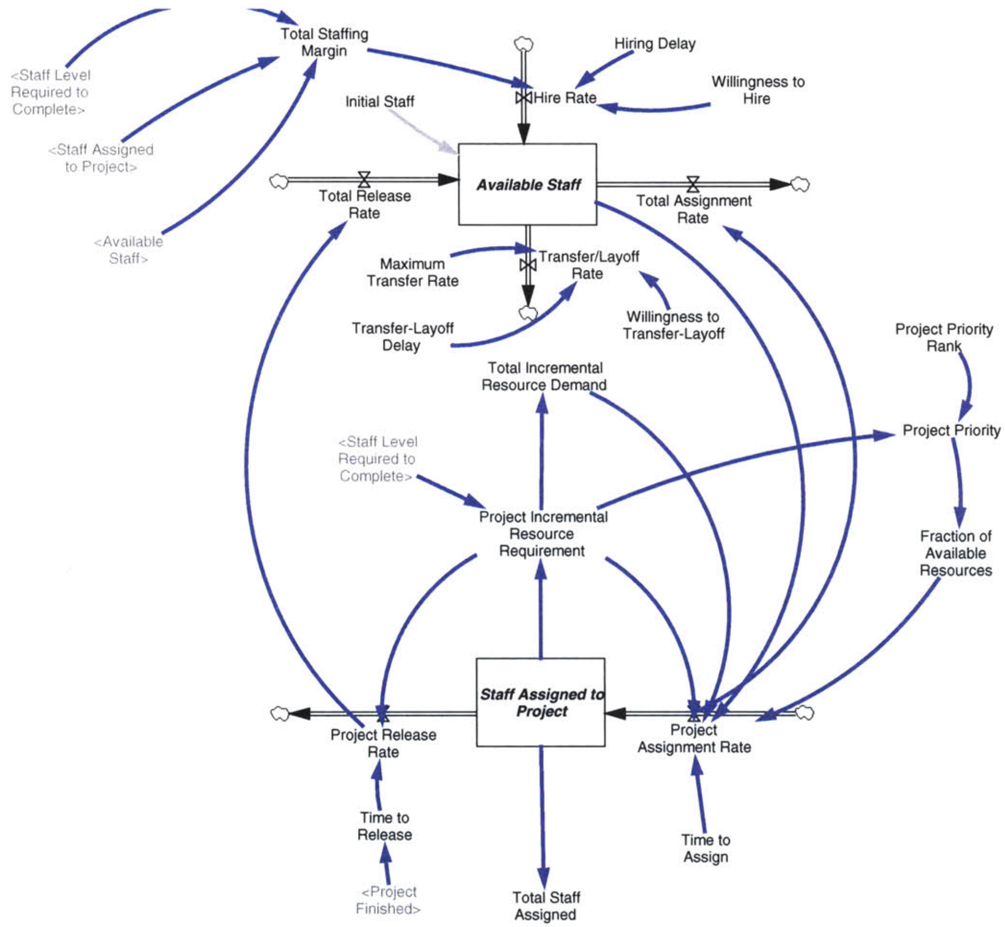
Multi-Project Model Sketch – Staffing



Command File – Multi-Project Slip Compare.cmd

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SIMULATE>SETVAL|technology maturity factor[J]=1
SIMULATE>SETVAL|complexity factor[A]=1
SIMULATE>SETVAL|complexity factor[B]=1
SIMULATE>SETVAL|complexity factor[C]=1
SIMULATE>SETVAL|complexity factor[D]=1
SIMULATE>SETVAL|complexity factor[E]=1
SIMULATE>SETVAL|complexity factor[F]=1
SIMULATE>SETVAL|complexity factor[G]=1
SIMULATE>SETVAL|complexity factor[H]=1
SIMULATE>SETVAL|complexity factor[I]=1
SIMULATE>SETVAL|complexity factor[J]=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on quality=1
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on productivity=1
SIMULATE>RUNNAME|slip_multi
MENU>RUN|O

SIMULATE>SETVAL|initial staff=62
SIMULATE>SETVAL|initial work to do[A]=288
SIMULATE>SETVAL|initial work to do[B]=288
SIMULATE>SETVAL|initial work to do[C]=288
SIMULATE>SETVAL|initial work to do[D]=288
SIMULATE>SETVAL|initial work to do[E]=288
SIMULATE>SETVAL|initial work to do[F]=288
SIMULATE>SETVAL|initial work to do[G]=288
SIMULATE>SETVAL|initial work to do[H]=288
SIMULATE>SETVAL|initial work to do[I]=288
SIMULATE>SETVAL|initial work to do[J]=288
SIMULATE>SETVAL|estimated rework[A]=32
SIMULATE>SETVAL|estimated rework[B]=32
SIMULATE>SETVAL|estimated rework[C]=32
SIMULATE>SETVAL|estimated rework[D]=32
SIMULATE>SETVAL|estimated rework[E]=32
SIMULATE>SETVAL|estimated rework[F]=32
SIMULATE>SETVAL|estimated rework[G]=32
SIMULATE>SETVAL|estimated rework[H]=32
SIMULATE>SETVAL|estimated rework[I]=32
SIMULATE>SETVAL|estimated rework[J]=32
SIMULATE>SETVAL|initial planned duration[A]=48
SIMULATE>SETVAL|initial planned duration[B]=48
SIMULATE>SETVAL|initial planned duration[C]=48
SIMULATE>SETVAL|initial planned duration[D]=48
SIMULATE>SETVAL|initial planned duration[E]=48
SIMULATE>SETVAL|initial planned duration[F]=48
SIMULATE>SETVAL|initial planned duration[G]=48
SIMULATE>SETVAL|initial planned duration[H]=48
SIMULATE>SETVAL|initial planned duration[I]=48
SIMULATE>SETVAL|initial planned duration[J]=48
SIMULATE>SETVAL|willingness to slip[A]=0
SIMULATE>SETVAL|willingness to slip[B]=0
SIMULATE>SETVAL|willingness to slip[C]=0
SIMULATE>SETVAL|willingness to slip[D]=0
SIMULATE>SETVAL|willingness to slip[E]=0
```

```
SIMULATE>SETVAL|willingness to slip[F]=0
SIMULATE>SETVAL|willingness to slip[G]=0
SIMULATE>SETVAL|willingness to slip[H]=0
SIMULATE>SETVAL|willingness to slip[I]=0
SIMULATE>SETVAL|willingness to slip[J]=0
SIMULATE>SETVAL|willingness to increase max staff[A]=0
SIMULATE>SETVAL|willingness to increase max staff[B]=0
SIMULATE>SETVAL|willingness to increase max staff[C]=0
SIMULATE>SETVAL|willingness to increase max staff[D]=0
SIMULATE>SETVAL|willingness to increase max staff[E]=0
SIMULATE>SETVAL|willingness to increase max staff[F]=0
SIMULATE>SETVAL|willingness to increase max staff[G]=0
SIMULATE>SETVAL|willingness to increase max staff[H]=0
SIMULATE>SETVAL|willingness to increase max staff[I]=0
SIMULATE>SETVAL|willingness to increase max staff[J]=0
SIMULATE>SETVAL|normal quality[A]=0.9
SIMULATE>SETVAL|normal quality[B]=0.9
SIMULATE>SETVAL|normal quality[C]=0.9
SIMULATE>SETVAL|normal quality[D]=0.9
SIMULATE>SETVAL|normal quality[E]=0.9
SIMULATE>SETVAL|normal quality[F]=0.9
SIMULATE>SETVAL|normal quality[G]=0.9
SIMULATE>SETVAL|normal quality[H]=0.9
SIMULATE>SETVAL|normal quality[I]=0.9
SIMULATE>SETVAL|normal quality[J]=0.9
SIMULATE>SETVAL|normal productivity[A]=0.08333
SIMULATE>SETVAL|normal productivity[B]=0.08333
SIMULATE>SETVAL|normal productivity[C]=0.08333
SIMULATE>SETVAL|normal productivity[D]=0.08333
SIMULATE>SETVAL|normal productivity[E]=0.08333
SIMULATE>SETVAL|normal productivity[F]=0.08333
SIMULATE>SETVAL|normal productivity[G]=0.08333
SIMULATE>SETVAL|normal productivity[H]=0.08333
SIMULATE>SETVAL|normal productivity[I]=0.08333
SIMULATE>SETVAL|normal productivity[J]=0.08333
SIMULATE>SETVAL|maximum time to discover rework=18
SIMULATE>SETVAL|technology maturity factor[A]=1
SIMULATE>SETVAL|technology maturity factor[B]=1
SIMULATE>SETVAL|technology maturity factor[C]=1
SIMULATE>SETVAL|technology maturity factor[D]=1
SIMULATE>SETVAL|technology maturity factor[E]=1
SIMULATE>SETVAL|technology maturity factor[F]=1
SIMULATE>SETVAL|technology maturity factor[G]=1
SIMULATE>SETVAL|technology maturity factor[H]=1
SIMULATE>SETVAL|technology maturity factor[I]=1
SIMULATE>SETVAL|technology maturity factor[J]=1
SIMULATE>SETVAL|complexity factor[A]=1
SIMULATE>SETVAL|complexity factor[B]=1
SIMULATE>SETVAL|complexity factor[C]=1
SIMULATE>SETVAL|complexity factor[D]=1
SIMULATE>SETVAL|complexity factor[E]=1
SIMULATE>SETVAL|complexity factor[F]=1
SIMULATE>SETVAL|complexity factor[G]=1
SIMULATE>SETVAL|complexity factor[H]=1
SIMULATE>SETVAL|complexity factor[I]=1
SIMULATE>SETVAL|complexity factor[J]=1
```

```
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on quality=1
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on productivity=1
SIMULATE>RUNNAME|no slip_multi 62
MENU>RUN|O

SIMULATE>SETVAL|initial staff=88
SIMULATE>SETVAL|initial work to do[A]=288
SIMULATE>SETVAL|initial work to do[B]=288
SIMULATE>SETVAL|initial work to do[C]=288
SIMULATE>SETVAL|initial work to do[D]=288
SIMULATE>SETVAL|initial work to do[E]=288
SIMULATE>SETVAL|initial work to do[F]=288
SIMULATE>SETVAL|initial work to do[G]=288
SIMULATE>SETVAL|initial work to do[H]=288
SIMULATE>SETVAL|initial work to do[I]=288
SIMULATE>SETVAL|initial work to do[J]=288
SIMULATE>SETVAL|estimated rework[A]=32
SIMULATE>SETVAL|estimated rework[B]=32
SIMULATE>SETVAL|estimated rework[C]=32
SIMULATE>SETVAL|estimated rework[D]=32
SIMULATE>SETVAL|estimated rework[E]=32
SIMULATE>SETVAL|estimated rework[F]=32
SIMULATE>SETVAL|estimated rework[G]=32
SIMULATE>SETVAL|estimated rework[H]=32
SIMULATE>SETVAL|estimated rework[I]=32
SIMULATE>SETVAL|estimated rework[J]=32
SIMULATE>SETVAL|initial planned duration[A]=48
SIMULATE>SETVAL|initial planned duration[B]=48
SIMULATE>SETVAL|initial planned duration[C]=48
SIMULATE>SETVAL|initial planned duration[D]=48
SIMULATE>SETVAL|initial planned duration[E]=48
SIMULATE>SETVAL|initial planned duration[F]=48
SIMULATE>SETVAL|initial planned duration[G]=48
SIMULATE>SETVAL|initial planned duration[H]=48
SIMULATE>SETVAL|initial planned duration[I]=48
SIMULATE>SETVAL|initial planned duration[J]=48
SIMULATE>SETVAL|willingness to slip[A]=0
SIMULATE>SETVAL|willingness to slip[B]=0
SIMULATE>SETVAL|willingness to slip[C]=0
SIMULATE>SETVAL|willingness to slip[D]=0
SIMULATE>SETVAL|willingness to slip[E]=0
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SIMULATE>SETVAL|willingness to slip[G]=0
SIMULATE>SETVAL|willingness to slip[H]=0
SIMULATE>SETVAL|willingness to slip[I]=0
SIMULATE>SETVAL|willingness to slip[J]=0
SIMULATE>SETVAL|willingness to increase max staff[A]=0
SIMULATE>SETVAL|willingness to increase max staff[B]=0
SIMULATE>SETVAL|willingness to increase max staff[C]=0
SIMULATE>SETVAL|willingness to increase max staff[D]=0
SIMULATE>SETVAL|willingness to increase max staff[E]=0
SIMULATE>SETVAL|willingness to increase max staff[F]=0
SIMULATE>SETVAL|willingness to increase max staff[G]=0
SIMULATE>SETVAL|willingness to increase max staff[H]=0
```

```
SIMULATE>SETVAL|willingness to increase max staff[I]=0
SIMULATE>SETVAL|willingness to increase max staff[J]=0
SIMULATE>SETVAL|normal quality[A]=0.9
SIMULATE>SETVAL|normal quality[B]=0.9
SIMULATE>SETVAL|normal quality[C]=0.9
SIMULATE>SETVAL|normal quality[D]=0.9
SIMULATE>SETVAL|normal quality[E]=0.9
SIMULATE>SETVAL|normal quality[F]=0.9
SIMULATE>SETVAL|normal quality[G]=0.9
SIMULATE>SETVAL|normal quality[H]=0.9
SIMULATE>SETVAL|normal quality[I]=0.9
SIMULATE>SETVAL|normal quality[J]=0.9
SIMULATE>SETVAL|normal productivity[A]=0.08333
SIMULATE>SETVAL|normal productivity[B]=0.08333
SIMULATE>SETVAL|normal productivity[C]=0.08333
SIMULATE>SETVAL|normal productivity[D]=0.08333
SIMULATE>SETVAL|normal productivity[E]=0.08333
SIMULATE>SETVAL|normal productivity[F]=0.08333
SIMULATE>SETVAL|normal productivity[G]=0.08333
SIMULATE>SETVAL|normal productivity[H]=0.08333
SIMULATE>SETVAL|normal productivity[I]=0.08333
SIMULATE>SETVAL|normal productivity[J]=0.08333
SIMULATE>SETVAL|maximum time to discover rework=18
SIMULATE>SETVAL|technology maturity factor[A]=1
SIMULATE>SETVAL|technology maturity factor[B]=1
SIMULATE>SETVAL|technology maturity factor[C]=1
SIMULATE>SETVAL|technology maturity factor[D]=1
SIMULATE>SETVAL|technology maturity factor[E]=1
SIMULATE>SETVAL|technology maturity factor[F]=1
SIMULATE>SETVAL|technology maturity factor[G]=1
SIMULATE>SETVAL|technology maturity factor[H]=1
SIMULATE>SETVAL|technology maturity factor[I]=1
SIMULATE>SETVAL|technology maturity factor[J]=1
SIMULATE>SETVAL|complexity factor[A]=1
SIMULATE>SETVAL|complexity factor[B]=1
SIMULATE>SETVAL|complexity factor[C]=1
SIMULATE>SETVAL|complexity factor[D]=1
SIMULATE>SETVAL|complexity factor[E]=1
SIMULATE>SETVAL|complexity factor[F]=1
SIMULATE>SETVAL|complexity factor[G]=1
SIMULATE>SETVAL|complexity factor[H]=1
SIMULATE>SETVAL|complexity factor[I]=1
SIMULATE>SETVAL|complexity factor[J]=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on quality=1
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on productivity=1
SIMULATE>RUNNAME|no slip_multi 88
MENU>RUN|O

SIMULATE>SETVAL|initial staff=96
SIMULATE>SETVAL|initial work to do[A]=288
SIMULATE>SETVAL|initial work to do[B]=288
SIMULATE>SETVAL|initial work to do[C]=288
SIMULATE>SETVAL|initial work to do[D]=288
SIMULATE>SETVAL|initial work to do[E]=288
```

```
SIMULATE>SETVAL|initial work to do[F]=288
SIMULATE>SETVAL|initial work to do[G]=288
SIMULATE>SETVAL|initial work to do[H]=288
SIMULATE>SETVAL|initial work to do[I]=288
SIMULATE>SETVAL|initial work to do[J]=288
SIMULATE>SETVAL|estimated rework[A]=32
SIMULATE>SETVAL|estimated rework[B]=32
SIMULATE>SETVAL|estimated rework[C]=32
SIMULATE>SETVAL|estimated rework[D]=32
SIMULATE>SETVAL|estimated rework[E]=32
SIMULATE>SETVAL|estimated rework[F]=32
SIMULATE>SETVAL|estimated rework[G]=32
SIMULATE>SETVAL|estimated rework[H]=32
SIMULATE>SETVAL|estimated rework[I]=32
SIMULATE>SETVAL|estimated rework[J]=32
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SIMULATE>SETVAL|initial planned duration[B]=48
SIMULATE>SETVAL|initial planned duration[C]=48
SIMULATE>SETVAL|initial planned duration[D]=48
SIMULATE>SETVAL|initial planned duration[E]=48
SIMULATE>SETVAL|initial planned duration[F]=48
SIMULATE>SETVAL|initial planned duration[G]=48
SIMULATE>SETVAL|initial planned duration[H]=48
SIMULATE>SETVAL|initial planned duration[I]=48
SIMULATE>SETVAL|initial planned duration[J]=48
SIMULATE>SETVAL|willingness to slip[A]=0
SIMULATE>SETVAL|willingness to slip[B]=0
SIMULATE>SETVAL|willingness to slip[C]=0
SIMULATE>SETVAL|willingness to slip[D]=0
SIMULATE>SETVAL|willingness to slip[E]=0
SIMULATE>SETVAL|willingness to slip[F]=0
SIMULATE>SETVAL|willingness to slip[G]=0
SIMULATE>SETVAL|willingness to slip[H]=0
SIMULATE>SETVAL|willingness to slip[I]=0
SIMULATE>SETVAL|willingness to slip[J]=0
SIMULATE>SETVAL|willingness to increase max staff[A]=0
SIMULATE>SETVAL|willingness to increase max staff[B]=0
SIMULATE>SETVAL|willingness to increase max staff[C]=0
SIMULATE>SETVAL|willingness to increase max staff[D]=0
SIMULATE>SETVAL|willingness to increase max staff[E]=0
SIMULATE>SETVAL|willingness to increase max staff[F]=0
SIMULATE>SETVAL|willingness to increase max staff[G]=0
SIMULATE>SETVAL|willingness to increase max staff[H]=0
SIMULATE>SETVAL|willingness to increase max staff[I]=0
SIMULATE>SETVAL|willingness to increase max staff[J]=0
SIMULATE>SETVAL|normal quality[A]=0.9
SIMULATE>SETVAL|normal quality[B]=0.9
SIMULATE>SETVAL|normal quality[C]=0.9
SIMULATE>SETVAL|normal quality[D]=0.9
SIMULATE>SETVAL|normal quality[E]=0.9
SIMULATE>SETVAL|normal quality[F]=0.9
SIMULATE>SETVAL|normal quality[G]=0.9
SIMULATE>SETVAL|normal quality[H]=0.9
SIMULATE>SETVAL|normal quality[I]=0.9
SIMULATE>SETVAL|normal quality[J]=0.9
SIMULATE>SETVAL|normal productivity[A]=0.08333
```

```
SIMULATE>SETVAL|normal productivity[B]=0.08333
SIMULATE>SETVAL|normal productivity[C]=0.08333
SIMULATE>SETVAL|normal productivity[D]=0.08333
SIMULATE>SETVAL|normal productivity[E]=0.08333
SIMULATE>SETVAL|normal productivity[F]=0.08333
SIMULATE>SETVAL|normal productivity[G]=0.08333
SIMULATE>SETVAL|normal productivity[H]=0.08333
SIMULATE>SETVAL|normal productivity[I]=0.08333
SIMULATE>SETVAL|normal productivity[J]=0.08333
SIMULATE>SETVAL|maximum time to discover rework=18
SIMULATE>SETVAL|technology maturity factor[A]=1
SIMULATE>SETVAL|technology maturity factor[B]=1
SIMULATE>SETVAL|technology maturity factor[C]=1
SIMULATE>SETVAL|technology maturity factor[D]=1
SIMULATE>SETVAL|technology maturity factor[E]=1
SIMULATE>SETVAL|technology maturity factor[F]=1
SIMULATE>SETVAL|technology maturity factor[G]=1
SIMULATE>SETVAL|technology maturity factor[H]=1
SIMULATE>SETVAL|technology maturity factor[I]=1
SIMULATE>SETVAL|technology maturity factor[J]=1
SIMULATE>SETVAL|complexity factor[A]=1
SIMULATE>SETVAL|complexity factor[B]=1
SIMULATE>SETVAL|complexity factor[C]=1
SIMULATE>SETVAL|complexity factor[D]=1
SIMULATE>SETVAL|complexity factor[E]=1
SIMULATE>SETVAL|complexity factor[F]=1
SIMULATE>SETVAL|complexity factor[G]=1
SIMULATE>SETVAL|complexity factor[H]=1
SIMULATE>SETVAL|complexity factor[I]=1
SIMULATE>SETVAL|complexity factor[J]=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on quality=1
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on productivity=1
SIMULATE>RUNNAME|no slip_multi 96
MENU>RUN|O
```

Command File – Multi-Project Resource Experiments.cmd

```
SIMULATE>SETVAL|initial staff=80
SIMULATE>SETVAL|initial work to do[A]=288
SIMULATE>SETVAL|initial work to do[B]=288
SIMULATE>SETVAL|initial work to do[C]=288
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SIMULATE>SETVAL|initial work to do[E]=288
SIMULATE>SETVAL|initial work to do[F]=288
SIMULATE>SETVAL|initial work to do[G]=288
SIMULATE>SETVAL|initial work to do[H]=288
SIMULATE>SETVAL|initial work to do[I]=288
SIMULATE>SETVAL|initial work to do[J]=288
SIMULATE>SETVAL|estimated rework[A]=32
SIMULATE>SETVAL|estimated rework[B]=32
SIMULATE>SETVAL|estimated rework[C]=32
SIMULATE>SETVAL|estimated rework[D]=32
SIMULATE>SETVAL|estimated rework[E]=32
SIMULATE>SETVAL|estimated rework[F]=32
SIMULATE>SETVAL|estimated rework[G]=32
SIMULATE>SETVAL|estimated rework[H]=32
SIMULATE>SETVAL|estimated rework[I]=32
SIMULATE>SETVAL|estimated rework[J]=32
SIMULATE>SETVAL|initial planned duration[A]=48
SIMULATE>SETVAL|initial planned duration[B]=48
SIMULATE>SETVAL|initial planned duration[C]=48
SIMULATE>SETVAL|initial planned duration[D]=48
SIMULATE>SETVAL|initial planned duration[E]=48
SIMULATE>SETVAL|initial planned duration[F]=48
SIMULATE>SETVAL|initial planned duration[G]=48
SIMULATE>SETVAL|initial planned duration[H]=48
SIMULATE>SETVAL|initial planned duration[I]=48
SIMULATE>SETVAL|initial planned duration[J]=48
SIMULATE>SETVAL|willingness to slip[A]=0
SIMULATE>SETVAL|willingness to slip[B]=0
SIMULATE>SETVAL|willingness to slip[C]=0
SIMULATE>SETVAL|willingness to slip[D]=0
SIMULATE>SETVAL|willingness to slip[E]=0
SIMULATE>SETVAL|willingness to slip[F]=0
SIMULATE>SETVAL|willingness to slip[G]=0
SIMULATE>SETVAL|willingness to slip[H]=0
SIMULATE>SETVAL|willingness to slip[I]=0
SIMULATE>SETVAL|willingness to slip[J]=0
SIMULATE>SETVAL|willingness to increase max staff[A]=1
SIMULATE>SETVAL|willingness to increase max staff[B]=1
SIMULATE>SETVAL|willingness to increase max staff[C]=1
SIMULATE>SETVAL|willingness to increase max staff[D]=1
SIMULATE>SETVAL|willingness to increase max staff[E]=1
SIMULATE>SETVAL|willingness to increase max staff[F]=1
SIMULATE>SETVAL|willingness to increase max staff[G]=1
SIMULATE>SETVAL|willingness to increase max staff[H]=1
SIMULATE>SETVAL|willingness to increase max staff[I]=1
SIMULATE>SETVAL|willingness to increase max staff[J]=1
SIMULATE>SETVAL|normal quality[A]=0.9
SIMULATE>SETVAL|normal quality[B]=0.9
```

```
SIMULATE>SETVAL|normal quality[C]=0.9
SIMULATE>SETVAL|normal quality[D]=0.9
SIMULATE>SETVAL|normal quality[E]=0.9
SIMULATE>SETVAL|normal quality[F]=0.9
SIMULATE>SETVAL|normal quality[G]=0.9
SIMULATE>SETVAL|normal quality[H]=0.9
SIMULATE>SETVAL|normal quality[I]=0.9
SIMULATE>SETVAL|normal quality[J]=0.9
SIMULATE>SETVAL|normal productivity[A]=0.08333
SIMULATE>SETVAL|normal productivity[B]=0.08333
SIMULATE>SETVAL|normal productivity[C]=0.08333
SIMULATE>SETVAL|normal productivity[D]=0.08333
SIMULATE>SETVAL|normal productivity[E]=0.08333
SIMULATE>SETVAL|normal productivity[F]=0.08333
SIMULATE>SETVAL|normal productivity[G]=0.08333
SIMULATE>SETVAL|normal productivity[H]=0.08333
SIMULATE>SETVAL|normal productivity[I]=0.08333
SIMULATE>SETVAL|normal productivity[J]=0.08333
SIMULATE>SETVAL|maximum time to discover rework=18
SIMULATE>SETVAL|technology maturity factor[A]=1
SIMULATE>SETVAL|technology maturity factor[B]=.9
SIMULATE>SETVAL|technology maturity factor[C]=1
SIMULATE>SETVAL|technology maturity factor[D]=1
SIMULATE>SETVAL|technology maturity factor[E]=1
SIMULATE>SETVAL|technology maturity factor[F]=1
SIMULATE>SETVAL|technology maturity factor[G]=1
SIMULATE>SETVAL|technology maturity factor[H]=1
SIMULATE>SETVAL|technology maturity factor[I]=1
SIMULATE>SETVAL|technology maturity factor[J]=1
SIMULATE>SETVAL|complexity factor[A]=1
SIMULATE>SETVAL|complexity factor[B]=.9
SIMULATE>SETVAL|complexity factor[C]=1
SIMULATE>SETVAL|complexity factor[D]=1
SIMULATE>SETVAL|complexity factor[E]=1
SIMULATE>SETVAL|complexity factor[F]=1
SIMULATE>SETVAL|complexity factor[G]=1
SIMULATE>SETVAL|complexity factor[H]=1
SIMULATE>SETVAL|complexity factor[I]=1
SIMULATE>SETVAL|complexity factor[J]=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on quality=1
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on productivity=1
SIMULATE>RUNNAME|case 1a (TM,C=.9,AS=80)
MENU>RUN|O

SIMULATE>SETVAL|initial staff=80
SIMULATE>SETVAL|initial work to do[A]=288
SIMULATE>SETVAL|initial work to do[B]=288
SIMULATE>SETVAL|initial work to do[C]=288
SIMULATE>SETVAL|initial work to do[D]=288
SIMULATE>SETVAL|initial work to do[E]=288
SIMULATE>SETVAL|initial work to do[F]=288
SIMULATE>SETVAL|initial work to do[G]=288
SIMULATE>SETVAL|initial work to do[H]=288
SIMULATE>SETVAL|initial work to do[I]=288
```

```
SIMULATE>SETVAL|initial work to do[J]=288
SIMULATE>SETVAL|estimated rework[A]=32
SIMULATE>SETVAL|estimated rework[B]=32
SIMULATE>SETVAL|estimated rework[C]=32
SIMULATE>SETVAL|estimated rework[D]=32
SIMULATE>SETVAL|estimated rework[E]=32
SIMULATE>SETVAL|estimated rework[F]=32
SIMULATE>SETVAL|estimated rework[G]=32
SIMULATE>SETVAL|estimated rework[H]=32
SIMULATE>SETVAL|estimated rework[I]=32
SIMULATE>SETVAL|estimated rework[J]=32
SIMULATE>SETVAL|initial planned duration[A]=48
SIMULATE>SETVAL|initial planned duration[B]=48
SIMULATE>SETVAL|initial planned duration[C]=48
SIMULATE>SETVAL|initial planned duration[D]=48
SIMULATE>SETVAL|initial planned duration[E]=48
SIMULATE>SETVAL|initial planned duration[F]=48
SIMULATE>SETVAL|initial planned duration[G]=48
SIMULATE>SETVAL|initial planned duration[H]=48
SIMULATE>SETVAL|initial planned duration[I]=48
SIMULATE>SETVAL|initial planned duration[J]=48
SIMULATE>SETVAL|willingness to slip[A]=0
SIMULATE>SETVAL|willingness to slip[B]=0
SIMULATE>SETVAL|willingness to slip[C]=0
SIMULATE>SETVAL|willingness to slip[D]=0
SIMULATE>SETVAL|willingness to slip[E]=0
SIMULATE>SETVAL|willingness to slip[F]=0
SIMULATE>SETVAL|willingness to slip[G]=0
SIMULATE>SETVAL|willingness to slip[H]=0
SIMULATE>SETVAL|willingness to slip[I]=0
SIMULATE>SETVAL|willingness to slip[J]=0
SIMULATE>SETVAL|willingness to increase max staff[A]=1
SIMULATE>SETVAL|willingness to increase max staff[B]=1
SIMULATE>SETVAL|willingness to increase max staff[C]=1
SIMULATE>SETVAL|willingness to increase max staff[D]=1
SIMULATE>SETVAL|willingness to increase max staff[E]=1
SIMULATE>SETVAL|willingness to increase max staff[F]=1
SIMULATE>SETVAL|willingness to increase max staff[G]=1
SIMULATE>SETVAL|willingness to increase max staff[H]=1
SIMULATE>SETVAL|willingness to increase max staff[I]=1
SIMULATE>SETVAL|willingness to increase max staff[J]=1
SIMULATE>SETVAL|normal quality[A]=0.9
SIMULATE>SETVAL|normal quality[B]=0.9
SIMULATE>SETVAL|normal quality[C]=0.9
SIMULATE>SETVAL|normal quality[D]=0.9
SIMULATE>SETVAL|normal quality[E]=0.9
SIMULATE>SETVAL|normal quality[F]=0.9
SIMULATE>SETVAL|normal quality[G]=0.9
SIMULATE>SETVAL|normal quality[H]=0.9
SIMULATE>SETVAL|normal quality[I]=0.9
SIMULATE>SETVAL|normal quality[J]=0.9
SIMULATE>SETVAL|normal productivity[A]=0.08333
SIMULATE>SETVAL|normal productivity[B]=0.08333
SIMULATE>SETVAL|normal productivity[C]=0.08333
SIMULATE>SETVAL|normal productivity[D]=0.08333
SIMULATE>SETVAL|normal productivity[E]=0.08333
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SIMULATE>SETVAL|normal productivity[F]=0.08333
SIMULATE>SETVAL|normal productivity[G]=0.08333
SIMULATE>SETVAL|normal productivity[H]=0.08333
SIMULATE>SETVAL|normal productivity[I]=0.08333
SIMULATE>SETVAL|normal productivity[J]=0.08333
SIMULATE>SETVAL|maximum time to discover rework=18
SIMULATE>SETVAL|technology maturity factor[A]=1
SIMULATE>SETVAL|technology maturity factor[B]=.8
SIMULATE>SETVAL|technology maturity factor[C]=1
SIMULATE>SETVAL|technology maturity factor[D]=1
SIMULATE>SETVAL|technology maturity factor[E]=1
SIMULATE>SETVAL|technology maturity factor[F]=1
SIMULATE>SETVAL|technology maturity factor[G]=1
SIMULATE>SETVAL|technology maturity factor[H]=1
SIMULATE>SETVAL|technology maturity factor[I]=1
SIMULATE>SETVAL|technology maturity factor[J]=1
SIMULATE>SETVAL|complexity factor[A]=1
SIMULATE>SETVAL|complexity factor[B]=.8
SIMULATE>SETVAL|complexity factor[C]=1
SIMULATE>SETVAL|complexity factor[D]=1
SIMULATE>SETVAL|complexity factor[E]=1
SIMULATE>SETVAL|complexity factor[F]=1
SIMULATE>SETVAL|complexity factor[G]=1
SIMULATE>SETVAL|complexity factor[H]=1
SIMULATE>SETVAL|complexity factor[I]=1
SIMULATE>SETVAL|complexity factor[J]=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on quality=1
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on productivity=1
SIMULATE>RUNNAME|case 1b (TM,C=.8,AS=80)
MENU>RUN|O

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SIMULATE>SETVAL|initial work to do[B]=288
SIMULATE>SETVAL|initial work to do[C]=288
SIMULATE>SETVAL|initial work to do[D]=288
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SIMULATE>SETVAL|initial work to do[F]=288
SIMULATE>SETVAL|initial work to do[G]=288
SIMULATE>SETVAL|initial work to do[H]=288
SIMULATE>SETVAL|initial work to do[I]=288
SIMULATE>SETVAL|initial work to do[J]=288
SIMULATE>SETVAL|estimated rework[A]=32
SIMULATE>SETVAL|estimated rework[B]=32
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SIMULATE>SETVAL|estimated rework[D]=32
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SIMULATE>SETVAL|estimated rework[F]=32
SIMULATE>SETVAL|estimated rework[G]=32
SIMULATE>SETVAL|estimated rework[H]=32
SIMULATE>SETVAL|estimated rework[I]=32
SIMULATE>SETVAL|estimated rework[J]=32
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SIMULATE>SETVAL|initial planned duration[B]=48

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SIMULATE>SETVAL|initial planned duration[C]=48
SIMULATE>SETVAL|initial planned duration[D]=48
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SIMULATE>SETVAL|initial planned duration[G]=48
SIMULATE>SETVAL|initial planned duration[H]=48
SIMULATE>SETVAL|initial planned duration[I]=48
SIMULATE>SETVAL|initial planned duration[J]=48
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SIMULATE>SETVAL|willingness to slip[B]=0
SIMULATE>SETVAL|willingness to slip[C]=0
SIMULATE>SETVAL|willingness to slip[D]=0
SIMULATE>SETVAL|willingness to slip[E]=0
SIMULATE>SETVAL|willingness to slip[F]=0
SIMULATE>SETVAL|willingness to slip[G]=0
SIMULATE>SETVAL|willingness to slip[H]=0
SIMULATE>SETVAL|willingness to slip[I]=0
SIMULATE>SETVAL|willingness to slip[J]=0
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SIMULATE>SETVAL|willingness to increase max staff[B]=1
SIMULATE>SETVAL|willingness to increase max staff[C]=1
SIMULATE>SETVAL|willingness to increase max staff[D]=1
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SIMULATE>SETVAL|willingness to increase max staff[I]=1
SIMULATE>SETVAL|willingness to increase max staff[J]=1
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SIMULATE>SETVAL|normal quality[G]=0.9
SIMULATE>SETVAL|normal quality[H]=0.9
SIMULATE>SETVAL|normal quality[I]=0.9
SIMULATE>SETVAL|normal quality[J]=0.9
SIMULATE>SETVAL|normal productivity[A]=0.08333
SIMULATE>SETVAL|normal productivity[B]=0.08333
SIMULATE>SETVAL|normal productivity[C]=0.08333
SIMULATE>SETVAL|normal productivity[D]=0.08333
SIMULATE>SETVAL|normal productivity[E]=0.08333
SIMULATE>SETVAL|normal productivity[F]=0.08333
SIMULATE>SETVAL|normal productivity[G]=0.08333
SIMULATE>SETVAL|normal productivity[H]=0.08333
SIMULATE>SETVAL|normal productivity[I]=0.08333
SIMULATE>SETVAL|normal productivity[J]=0.08333
SIMULATE>SETVAL|maximum time to discover rework=18
SIMULATE>SETVAL|technology maturity factor[A]=1
SIMULATE>SETVAL|technology maturity factor[B]=.9
SIMULATE>SETVAL|technology maturity factor[C]=1
SIMULATE>SETVAL|technology maturity factor[D]=1
SIMULATE>SETVAL|technology maturity factor[E]=1
SIMULATE>SETVAL|technology maturity factor[F]=1
SIMULATE>SETVAL|technology maturity factor[G]=1
```

```
SIMULATE>SETVAL|technology maturity factor[H]=1
SIMULATE>SETVAL|technology maturity factor[I]=1
SIMULATE>SETVAL|technology maturity factor[J]=1
SIMULATE>SETVAL|complexity factor[A]=1
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SIMULATE>SETVAL|complexity factor[F]=1
SIMULATE>SETVAL|complexity factor[G]=1
SIMULATE>SETVAL|complexity factor[H]=1
SIMULATE>SETVAL|complexity factor[I]=1
SIMULATE>SETVAL|complexity factor[J]=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on quality=1
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on productivity=1
SIMULATE>RUNNAME|case 2a (TM,C=.9,AS=88)
MENU>RUN|O

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SIMULATE>SETVAL|initial work to do[B]=288
SIMULATE>SETVAL|initial work to do[C]=288
SIMULATE>SETVAL|initial work to do[D]=288
SIMULATE>SETVAL|initial work to do[E]=288
SIMULATE>SETVAL|initial work to do[F]=288
SIMULATE>SETVAL|initial work to do[G]=288
SIMULATE>SETVAL|initial work to do[H]=288
SIMULATE>SETVAL|initial work to do[I]=288
SIMULATE>SETVAL|initial work to do[J]=288
SIMULATE>SETVAL|estimated rework[A]=32
SIMULATE>SETVAL|estimated rework[B]=32
SIMULATE>SETVAL|estimated rework[C]=32
SIMULATE>SETVAL|estimated rework[D]=32
SIMULATE>SETVAL|estimated rework[E]=32
SIMULATE>SETVAL|estimated rework[F]=32
SIMULATE>SETVAL|estimated rework[G]=32
SIMULATE>SETVAL|estimated rework[H]=32
SIMULATE>SETVAL|estimated rework[I]=32
SIMULATE>SETVAL|estimated rework[J]=32
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SIMULATE>SETVAL|initial planned duration[D]=48
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SIMULATE>SETVAL|initial planned duration[G]=48
SIMULATE>SETVAL|initial planned duration[H]=48
SIMULATE>SETVAL|initial planned duration[I]=48
SIMULATE>SETVAL|initial planned duration[J]=48
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SIMULATE>SETVAL|willingness to slip[B]=0
SIMULATE>SETVAL|willingness to slip[C]=0
SIMULATE>SETVAL|willingness to slip[D]=0
SIMULATE>SETVAL|willingness to slip[E]=0
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SIMULATE>SETVAL|willingness to slip[F]=0
SIMULATE>SETVAL|willingness to slip[G]=0
SIMULATE>SETVAL|willingness to slip[H]=0
SIMULATE>SETVAL|willingness to slip[I]=0
SIMULATE>SETVAL|willingness to slip[J]=0
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SIMULATE>SETVAL|willingness to increase max staff[B]=1
SIMULATE>SETVAL|willingness to increase max staff[C]=1
SIMULATE>SETVAL|willingness to increase max staff[D]=1
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SIMULATE>SETVAL|willingness to increase max staff[I]=1
SIMULATE>SETVAL|willingness to increase max staff[J]=1
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SIMULATE>SETVAL|normal quality[D]=0.9
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SIMULATE>SETVAL|normal quality[G]=0.9
SIMULATE>SETVAL|normal quality[H]=0.9
SIMULATE>SETVAL|normal quality[I]=0.9
SIMULATE>SETVAL|normal quality[J]=0.9
SIMULATE>SETVAL|normal productivity[A]=0.08333
SIMULATE>SETVAL|normal productivity[B]=0.08333
SIMULATE>SETVAL|normal productivity[C]=0.08333
SIMULATE>SETVAL|normal productivity[D]=0.08333
SIMULATE>SETVAL|normal productivity[E]=0.08333
SIMULATE>SETVAL|normal productivity[F]=0.08333
SIMULATE>SETVAL|normal productivity[G]=0.08333
SIMULATE>SETVAL|normal productivity[H]=0.08333
SIMULATE>SETVAL|normal productivity[I]=0.08333
SIMULATE>SETVAL|normal productivity[J]=0.08333
SIMULATE>SETVAL|maximum time to discover rework=18
SIMULATE>SETVAL|technology maturity factor[A]=1
SIMULATE>SETVAL|technology maturity factor[B]=.8
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SIMULATE>SETVAL|technology maturity factor[I]=1
SIMULATE>SETVAL|technology maturity factor[J]=1
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SIMULATE>SETVAL|complexity factor[B]=.8
SIMULATE>SETVAL|complexity factor[C]=1
SIMULATE>SETVAL|complexity factor[D]=1
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SIMULATE>SETVAL|complexity factor[F]=1
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SIMULATE>SETVAL|complexity factor[H]=1
SIMULATE>SETVAL|complexity factor[I]=1
SIMULATE>SETVAL|complexity factor[J]=1

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SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on quality=1
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on productivity=1
SIMULATE>RUNNAME|case 2b (TM,C=.8,AS=88)
MENU>RUN|O

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SIMULATE>SETVAL|initial work to do[C]=288
SIMULATE>SETVAL|initial work to do[D]=288
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SIMULATE>SETVAL|initial work to do[G]=288
SIMULATE>SETVAL|initial work to do[H]=288
SIMULATE>SETVAL|initial work to do[I]=288
SIMULATE>SETVAL|initial work to do[J]=288
SIMULATE>SETVAL|estimated rework[A]=32
SIMULATE>SETVAL|estimated rework[B]=32
SIMULATE>SETVAL|estimated rework[C]=32
SIMULATE>SETVAL|estimated rework[D]=32
SIMULATE>SETVAL|estimated rework[E]=32
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SIMULATE>SETVAL|estimated rework[G]=32
SIMULATE>SETVAL|estimated rework[H]=32
SIMULATE>SETVAL|estimated rework[I]=32
SIMULATE>SETVAL|estimated rework[J]=32
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SIMULATE>SETVAL|initial planned duration[G]=48
SIMULATE>SETVAL|initial planned duration[H]=48
SIMULATE>SETVAL|initial planned duration[I]=48
SIMULATE>SETVAL|initial planned duration[J]=48
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SIMULATE>SETVAL|willingness to slip[C]=0
SIMULATE>SETVAL|willingness to slip[D]=0
SIMULATE>SETVAL|willingness to slip[E]=0
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SIMULATE>SETVAL|willingness to slip[G]=0
SIMULATE>SETVAL|willingness to slip[H]=0
SIMULATE>SETVAL|willingness to slip[I]=0
SIMULATE>SETVAL|willingness to slip[J]=0
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SIMULATE>SETVAL|willingness to increase max staff[B]=1
SIMULATE>SETVAL|willingness to increase max staff[C]=1
SIMULATE>SETVAL|willingness to increase max staff[D]=1
SIMULATE>SETVAL|willingness to increase max staff[E]=1
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SIMULATE>SETVAL|willingness to increase max staff[G]=1
SIMULATE>SETVAL|willingness to increase max staff[H]=1
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SIMULATE>SETVAL|normal quality[F]=0.9
SIMULATE>SETVAL|normal quality[G]=0.9
SIMULATE>SETVAL|normal quality[H]=0.9
SIMULATE>SETVAL|normal quality[I]=0.9
SIMULATE>SETVAL|normal quality[J]=0.9
SIMULATE>SETVAL|normal productivity[A]=0.08333
SIMULATE>SETVAL|normal productivity[B]=0.08333
SIMULATE>SETVAL|normal productivity[C]=0.08333
SIMULATE>SETVAL|normal productivity[D]=0.08333
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SIMULATE>SETVAL|normal productivity[F]=0.08333
SIMULATE>SETVAL|normal productivity[G]=0.08333
SIMULATE>SETVAL|normal productivity[H]=0.08333
SIMULATE>SETVAL|normal productivity[I]=0.08333
SIMULATE>SETVAL|normal productivity[J]=0.08333
SIMULATE>SETVAL|maximum time to discover rework=18
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SIMULATE>SETVAL|technology maturity factor[C]=1
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SIMULATE>SETVAL|technology maturity factor[I]=1
SIMULATE>SETVAL|technology maturity factor[J]=1
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SIMULATE>SETVAL|complexity factor[B]=.9
SIMULATE>SETVAL|complexity factor[C]=1
SIMULATE>SETVAL|complexity factor[D]=1
SIMULATE>SETVAL|complexity factor[E]=1
SIMULATE>SETVAL|complexity factor[F]=1
SIMULATE>SETVAL|complexity factor[G]=1
SIMULATE>SETVAL|complexity factor[H]=1
SIMULATE>SETVAL|complexity factor[I]=1
SIMULATE>SETVAL|complexity factor[J]=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on quality=1
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on productivity=1
SIMULATE>RUNNAME|case 3a (TM,C=.9,AS=96)
MENU>RUN|O

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SIMULATE>SETVAL|initial work to do[D]=288
SIMULATE>SETVAL|initial work to do[E]=288
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SIMULATE>SETVAL|initial work to do[H]=288
SIMULATE>SETVAL|initial work to do[I]=288
SIMULATE>SETVAL|initial work to do[J]=288
SIMULATE>SETVAL|estimated rework[A]=32
SIMULATE>SETVAL|estimated rework[B]=32
SIMULATE>SETVAL|estimated rework[C]=32
SIMULATE>SETVAL|estimated rework[D]=32
SIMULATE>SETVAL|estimated rework[E]=32
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SIMULATE>SETVAL|initial planned duration[I]=48
SIMULATE>SETVAL|initial planned duration[J]=48
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SIMULATE>SETVAL|willingness to slip[C]=0
SIMULATE>SETVAL|willingness to slip[D]=0
SIMULATE>SETVAL|willingness to slip[E]=0
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SIMULATE>SETVAL|willingness to slip[H]=0
SIMULATE>SETVAL|willingness to slip[I]=0
SIMULATE>SETVAL|willingness to slip[J]=0
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SIMULATE>SETVAL|willingness to increase max staff[J]=1
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SIMULATE>SETVAL|normal quality[D]=0.9
SIMULATE>SETVAL|normal quality[E]=0.9
SIMULATE>SETVAL|normal quality[F]=0.9
SIMULATE>SETVAL|normal quality[G]=0.9
SIMULATE>SETVAL|normal quality[H]=0.9
SIMULATE>SETVAL|normal quality[I]=0.9
SIMULATE>SETVAL|normal quality[J]=0.9
SIMULATE>SETVAL|normal productivity[A]=0.08333
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SIMULATE>SETVAL|normal productivity[B]=0.08333
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SIMULATE>SETVAL|normal productivity[D]=0.08333
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SIMULATE>SETVAL|normal productivity[F]=0.08333
SIMULATE>SETVAL|normal productivity[G]=0.08333
SIMULATE>SETVAL|normal productivity[H]=0.08333
SIMULATE>SETVAL|normal productivity[I]=0.08333
SIMULATE>SETVAL|normal productivity[J]=0.08333
SIMULATE>SETVAL|maximum time to discover rework=18
SIMULATE>SETVAL|technology maturity factor[A]=1
SIMULATE>SETVAL|technology maturity factor[B]=.8
SIMULATE>SETVAL|technology maturity factor[C]=1
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SIMULATE>SETVAL|technology maturity factor[J]=1
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SIMULATE>SETVAL|complexity factor[G]=1
SIMULATE>SETVAL|complexity factor[H]=1
SIMULATE>SETVAL|complexity factor[I]=1
SIMULATE>SETVAL|complexity factor[J]=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on quality=1
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on productivity=1
SIMULATE>RUNNAME|case 3b (TM,C=.8,AS=96)
MENU>RUN|O

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SIMULATE>SETVAL|initial work to do[B]=288
SIMULATE>SETVAL|initial work to do[C]=288
SIMULATE>SETVAL|initial work to do[D]=288
SIMULATE>SETVAL|initial work to do[E]=288
SIMULATE>SETVAL|initial work to do[F]=288
SIMULATE>SETVAL|initial work to do[G]=288
SIMULATE>SETVAL|initial work to do[H]=288
SIMULATE>SETVAL|initial work to do[I]=288
SIMULATE>SETVAL|initial work to do[J]=288
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SIMULATE>SETVAL|estimated rework[B]=32
SIMULATE>SETVAL|estimated rework[C]=32
SIMULATE>SETVAL|estimated rework[D]=32
SIMULATE>SETVAL|estimated rework[E]=32
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SIMULATE>SETVAL|estimated rework[G]=32
SIMULATE>SETVAL|estimated rework[H]=32
```

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SIMULATE>SETVAL|estimated rework[I]=32
SIMULATE>SETVAL|estimated rework[J]=32
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SIMULATE>SETVAL|initial planned duration[B]=48
SIMULATE>SETVAL|initial planned duration[C]=48
SIMULATE>SETVAL|initial planned duration[D]=48
SIMULATE>SETVAL|initial planned duration[E]=48
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SIMULATE>SETVAL|initial planned duration[I]=48
SIMULATE>SETVAL|initial planned duration[J]=48
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SIMULATE>SETVAL|willingness to slip[B]=0
SIMULATE>SETVAL|willingness to slip[C]=0
SIMULATE>SETVAL|willingness to slip[D]=0
SIMULATE>SETVAL|willingness to slip[E]=0
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SIMULATE>SETVAL|willingness to slip[H]=0
SIMULATE>SETVAL|willingness to slip[I]=0
SIMULATE>SETVAL|willingness to slip[J]=0
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SIMULATE>SETVAL|willingness to increase max staff[B]=1
SIMULATE>SETVAL|willingness to increase max staff[C]=1
SIMULATE>SETVAL|willingness to increase max staff[D]=1
SIMULATE>SETVAL|willingness to increase max staff[E]=1
SIMULATE>SETVAL|willingness to increase max staff[F]=1
SIMULATE>SETVAL|willingness to increase max staff[G]=1
SIMULATE>SETVAL|willingness to increase max staff[H]=1
SIMULATE>SETVAL|willingness to increase max staff[I]=1
SIMULATE>SETVAL|willingness to increase max staff[J]=1
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SIMULATE>SETVAL|normal quality[B]=0.9
SIMULATE>SETVAL|normal quality[C]=0.9
SIMULATE>SETVAL|normal quality[D]=0.9
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SIMULATE>SETVAL|normal quality[F]=0.9
SIMULATE>SETVAL|normal quality[G]=0.9
SIMULATE>SETVAL|normal quality[H]=0.9
SIMULATE>SETVAL|normal quality[I]=0.9
SIMULATE>SETVAL|normal quality[J]=0.9
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SIMULATE>SETVAL|normal productivity[B]=0.08333
SIMULATE>SETVAL|normal productivity[C]=0.08333
SIMULATE>SETVAL|normal productivity[D]=0.08333
SIMULATE>SETVAL|normal productivity[E]=0.08333
SIMULATE>SETVAL|normal productivity[F]=0.08333
SIMULATE>SETVAL|normal productivity[G]=0.08333
SIMULATE>SETVAL|normal productivity[H]=0.08333
SIMULATE>SETVAL|normal productivity[I]=0.08333
SIMULATE>SETVAL|normal productivity[J]=0.08333
SIMULATE>SETVAL|maximum time to discover rework=18
SIMULATE>SETVAL|technology maturity factor[A]=1
SIMULATE>SETVAL|technology maturity factor[B]=.9
SIMULATE>SETVAL|technology maturity factor[C]=1
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SIMULATE>SETVAL|technology maturity factor[F]=1
SIMULATE>SETVAL|technology maturity factor[G]=1
SIMULATE>SETVAL|technology maturity factor[H]=1
SIMULATE>SETVAL|technology maturity factor[I]=1
SIMULATE>SETVAL|technology maturity factor[J]=1
SIMULATE>SETVAL|complexity factor[A]=1
SIMULATE>SETVAL|complexity factor[B]=.9
SIMULATE>SETVAL|complexity factor[C]=1
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SIMULATE>SETVAL|complexity factor[F]=1
SIMULATE>SETVAL|complexity factor[G]=1
SIMULATE>SETVAL|complexity factor[H]=1
SIMULATE>SETVAL|complexity factor[I]=1
SIMULATE>SETVAL|complexity factor[J]=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on quality=1
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on productivity=1
SIMULATE>RUNNAME|case 4a (TM,C=.9,AS=104)
MENU>RUN|O

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SIMULATE>SETVAL|initial work to do[D]=288
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SIMULATE>SETVAL|initial work to do[H]=288
SIMULATE>SETVAL|initial work to do[I]=288
SIMULATE>SETVAL|initial work to do[J]=288
SIMULATE>SETVAL|estimated rework[A]=32
SIMULATE>SETVAL|estimated rework[B]=32
SIMULATE>SETVAL|estimated rework[C]=32
SIMULATE>SETVAL|estimated rework[D]=32
SIMULATE>SETVAL|estimated rework[E]=32
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SIMULATE>SETVAL|estimated rework[H]=32
SIMULATE>SETVAL|estimated rework[I]=32
SIMULATE>SETVAL|estimated rework[J]=32
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SIMULATE>SETVAL|initial planned duration[B]=48
SIMULATE>SETVAL|initial planned duration[C]=48
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SIMULATE>SETVAL|initial planned duration[G]=48
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SIMULATE>SETVAL|initial planned duration[I]=48
SIMULATE>SETVAL|initial planned duration[J]=48
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SIMULATE>SETVAL|willingness to slip[F]=0
SIMULATE>SETVAL|willingness to slip[G]=0
SIMULATE>SETVAL|willingness to slip[H]=0
SIMULATE>SETVAL|willingness to slip[I]=0
SIMULATE>SETVAL|willingness to slip[J]=0
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SIMULATE>SETVAL|willingness to increase max staff[B]=1
SIMULATE>SETVAL|willingness to increase max staff[C]=1
SIMULATE>SETVAL|willingness to increase max staff[D]=1
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SIMULATE>SETVAL|willingness to increase max staff[I]=1
SIMULATE>SETVAL|willingness to increase max staff[J]=1
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SIMULATE>SETVAL|normal quality[H]=0.9
SIMULATE>SETVAL|normal quality[I]=0.9
SIMULATE>SETVAL|normal quality[J]=0.9
SIMULATE>SETVAL|normal productivity[A]=0.08333
SIMULATE>SETVAL|normal productivity[B]=0.08333
SIMULATE>SETVAL|normal productivity[C]=0.08333
SIMULATE>SETVAL|normal productivity[D]=0.08333
SIMULATE>SETVAL|normal productivity[E]=0.08333
SIMULATE>SETVAL|normal productivity[F]=0.08333
SIMULATE>SETVAL|normal productivity[G]=0.08333
SIMULATE>SETVAL|normal productivity[H]=0.08333
SIMULATE>SETVAL|normal productivity[I]=0.08333
SIMULATE>SETVAL|normal productivity[J]=0.08333
SIMULATE>SETVAL|maximum time to discover rework=18
SIMULATE>SETVAL|technology maturity factor[A]=1
SIMULATE>SETVAL|technology maturity factor[B]=.8
SIMULATE>SETVAL|technology maturity factor[C]=1
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SIMULATE>SETVAL|technology maturity factor[G]=1
SIMULATE>SETVAL|technology maturity factor[H]=1
SIMULATE>SETVAL|technology maturity factor[I]=1
SIMULATE>SETVAL|technology maturity factor[J]=1
SIMULATE>SETVAL|complexity factor[A]=1
SIMULATE>SETVAL|complexity factor[B]=.8
SIMULATE>SETVAL|complexity factor[C]=1
SIMULATE>SETVAL|complexity factor[D]=1
SIMULATE>SETVAL|complexity factor[E]=1
SIMULATE>SETVAL|complexity factor[F]=1
```

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SIMULATE>SETVAL|complexity factor[H]=1
SIMULATE>SETVAL|complexity factor[I]=1
SIMULATE>SETVAL|complexity factor[J]=1
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SIMULATE>SETVAL|sensitivity for effect of quality on quality=0
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on quality=1
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on productivity=1
SIMULATE>RUNNAME|case 4b (TM,C=.8,AS=104)
MENU>RUN|O

SIMULATE>SETVAL|initial staff=112
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SIMULATE>SETVAL|initial work to do[C]=288
SIMULATE>SETVAL|initial work to do[D]=288
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SIMULATE>SETVAL|initial work to do[F]=288
SIMULATE>SETVAL|initial work to do[G]=288
SIMULATE>SETVAL|initial work to do[H]=288
SIMULATE>SETVAL|initial work to do[I]=288
SIMULATE>SETVAL|initial work to do[J]=288
SIMULATE>SETVAL|estimated rework[A]=32
SIMULATE>SETVAL|estimated rework[B]=32
SIMULATE>SETVAL|estimated rework[C]=32
SIMULATE>SETVAL|estimated rework[D]=32
SIMULATE>SETVAL|estimated rework[E]=32
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SIMULATE>SETVAL|estimated rework[H]=32
SIMULATE>SETVAL|estimated rework[I]=32
SIMULATE>SETVAL|estimated rework[J]=32
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SIMULATE>SETVAL|initial planned duration[C]=48
SIMULATE>SETVAL|initial planned duration[D]=48
SIMULATE>SETVAL|initial planned duration[E]=48
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SIMULATE>SETVAL|initial planned duration[G]=48
SIMULATE>SETVAL|initial planned duration[H]=48
SIMULATE>SETVAL|initial planned duration[I]=48
SIMULATE>SETVAL|initial planned duration[J]=48
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SIMULATE>SETVAL|willingness to slip[B]=0
SIMULATE>SETVAL|willingness to slip[C]=0
SIMULATE>SETVAL|willingness to slip[D]=0
SIMULATE>SETVAL|willingness to slip[E]=0
SIMULATE>SETVAL|willingness to slip[F]=0
SIMULATE>SETVAL|willingness to slip[G]=0
SIMULATE>SETVAL|willingness to slip[H]=0
SIMULATE>SETVAL|willingness to slip[I]=0
SIMULATE>SETVAL|willingness to slip[J]=0
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SIMULATE>SETVAL|willingness to increase max staff[B]=1
SIMULATE>SETVAL|willingness to increase max staff[C]=1
SIMULATE>SETVAL|willingness to increase max staff[D]=1
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SIMULATE>SETVAL|willingness to increase max staff[F]=1
SIMULATE>SETVAL|willingness to increase max staff[G]=1
SIMULATE>SETVAL|willingness to increase max staff[H]=1
SIMULATE>SETVAL|willingness to increase max staff[I]=1
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SIMULATE>SETVAL|normal quality[H]=0.9
SIMULATE>SETVAL|normal quality[I]=0.9
SIMULATE>SETVAL|normal quality[J]=0.9
SIMULATE>SETVAL|normal productivity[A]=0.08333
SIMULATE>SETVAL|normal productivity[B]=0.08333
SIMULATE>SETVAL|normal productivity[C]=0.08333
SIMULATE>SETVAL|normal productivity[D]=0.08333
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SIMULATE>SETVAL|normal productivity[G]=0.08333
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SIMULATE>SETVAL|normal productivity[I]=0.08333
SIMULATE>SETVAL|normal productivity[J]=0.08333
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SIMULATE>SETVAL|technology maturity factor[B]=.9
SIMULATE>SETVAL|technology maturity factor[C]=1
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SIMULATE>SETVAL|complexity factor[G]=1
SIMULATE>SETVAL|complexity factor[H]=1
SIMULATE>SETVAL|complexity factor[I]=1
SIMULATE>SETVAL|complexity factor[J]=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on quality=1
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on productivity=1
SIMULATE>RUNNAME|case 5a (TM,C=.9,AS=112)
MENU>RUN|O

SIMULATE>SETVAL|initial staff=112
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```
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SIMULATE>SETVAL|initial work to do[D]=288
SIMULATE>SETVAL|initial work to do[E]=288
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SIMULATE>SETVAL|initial work to do[H]=288
SIMULATE>SETVAL|initial work to do[I]=288
SIMULATE>SETVAL|initial work to do[J]=288
SIMULATE>SETVAL|estimated rework[A]=32
SIMULATE>SETVAL|estimated rework[B]=32
SIMULATE>SETVAL|estimated rework[C]=32
SIMULATE>SETVAL|estimated rework[D]=32
SIMULATE>SETVAL|estimated rework[E]=32
SIMULATE>SETVAL|estimated rework[F]=32
SIMULATE>SETVAL|estimated rework[G]=32
SIMULATE>SETVAL|estimated rework[H]=32
SIMULATE>SETVAL|estimated rework[I]=32
SIMULATE>SETVAL|estimated rework[J]=32
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SIMULATE>SETVAL|initial planned duration[F]=48
SIMULATE>SETVAL|initial planned duration[G]=48
SIMULATE>SETVAL|initial planned duration[H]=48
SIMULATE>SETVAL|initial planned duration[I]=48
SIMULATE>SETVAL|initial planned duration[J]=48
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SIMULATE>SETVAL|willingness to slip[B]=0
SIMULATE>SETVAL|willingness to slip[C]=0
SIMULATE>SETVAL|willingness to slip[D]=0
SIMULATE>SETVAL|willingness to slip[E]=0
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SIMULATE>SETVAL|willingness to slip[H]=0
SIMULATE>SETVAL|willingness to slip[I]=0
SIMULATE>SETVAL|willingness to slip[J]=0
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SIMULATE>SETVAL|willingness to increase max staff[B]=1
SIMULATE>SETVAL|willingness to increase max staff[C]=1
SIMULATE>SETVAL|willingness to increase max staff[D]=1
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SIMULATE>SETVAL|willingness to increase max staff[I]=1
SIMULATE>SETVAL|willingness to increase max staff[J]=1
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SIMULATE>SETVAL|normal quality[B]=0.9
SIMULATE>SETVAL|normal quality[C]=0.9
SIMULATE>SETVAL|normal quality[D]=0.9
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SIMULATE>SETVAL|normal quality[G]=0.9
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SIMULATE>SETVAL|normal quality[H]=0.9
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SIMULATE>SETVAL|normal productivity[B]=0.08333
SIMULATE>SETVAL|normal productivity[C]=0.08333
SIMULATE>SETVAL|normal productivity[D]=0.08333
SIMULATE>SETVAL|normal productivity[E]=0.08333
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SIMULATE>SETVAL|normal productivity[G]=0.08333
SIMULATE>SETVAL|normal productivity[H]=0.08333
SIMULATE>SETVAL|normal productivity[I]=0.08333
SIMULATE>SETVAL|normal productivity[J]=0.08333
SIMULATE>SETVAL|maximum time to discover rework=18
SIMULATE>SETVAL|technology maturity factor[A]=1
SIMULATE>SETVAL|technology maturity factor[B]=.8
SIMULATE>SETVAL|technology maturity factor[C]=1
SIMULATE>SETVAL|technology maturity factor[D]=1
SIMULATE>SETVAL|technology maturity factor[E]=1
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SIMULATE>SETVAL|technology maturity factor[G]=1
SIMULATE>SETVAL|technology maturity factor[H]=1
SIMULATE>SETVAL|technology maturity factor[I]=1
SIMULATE>SETVAL|technology maturity factor[J]=1
SIMULATE>SETVAL|complexity factor[A]=1
SIMULATE>SETVAL|complexity factor[B]=.8
SIMULATE>SETVAL|complexity factor[C]=1
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SIMULATE>SETVAL|complexity factor[H]=1
SIMULATE>SETVAL|complexity factor[I]=1
SIMULATE>SETVAL|complexity factor[J]=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on quality=1
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on productivity=1
SIMULATE>RUNNAME|case 5b (TM,C=.8,AS=112)
MENU>RUN|O

SIMULATE>SETVAL|initial staff=120
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SIMULATE>SETVAL|initial work to do[B]=288
SIMULATE>SETVAL|initial work to do[C]=288
SIMULATE>SETVAL|initial work to do[D]=288
SIMULATE>SETVAL|initial work to do[E]=288
SIMULATE>SETVAL|initial work to do[F]=288
SIMULATE>SETVAL|initial work to do[G]=288
SIMULATE>SETVAL|initial work to do[H]=288
SIMULATE>SETVAL|initial work to do[I]=288
SIMULATE>SETVAL|initial work to do[J]=288
SIMULATE>SETVAL|estimated rework[A]=32
SIMULATE>SETVAL|estimated rework[B]=32
SIMULATE>SETVAL|estimated rework[C]=32
SIMULATE>SETVAL|estimated rework[D]=32
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SIMULATE>SETVAL|estimated rework[E]=32
SIMULATE>SETVAL|estimated rework[F]=32
SIMULATE>SETVAL|estimated rework[G]=32
SIMULATE>SETVAL|estimated rework[H]=32
SIMULATE>SETVAL|estimated rework[I]=32
SIMULATE>SETVAL|estimated rework[J]=32
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SIMULATE>SETVAL|initial planned duration[H]=48
SIMULATE>SETVAL|initial planned duration[I]=48
SIMULATE>SETVAL|initial planned duration[J]=48
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SIMULATE>SETVAL|willingness to slip[B]=0
SIMULATE>SETVAL|willingness to slip[C]=0
SIMULATE>SETVAL|willingness to slip[D]=0
SIMULATE>SETVAL|willingness to slip[E]=0
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SIMULATE>SETVAL|willingness to slip[H]=0
SIMULATE>SETVAL|willingness to slip[I]=0
SIMULATE>SETVAL|willingness to slip[J]=0
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SIMULATE>SETVAL|willingness to increase max staff[B]=1
SIMULATE>SETVAL|willingness to increase max staff[C]=1
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SIMULATE>SETVAL|willingness to increase max staff[I]=1
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SIMULATE>SETVAL|normal quality[H]=0.9
SIMULATE>SETVAL|normal quality[I]=0.9
SIMULATE>SETVAL|normal quality[J]=0.9
SIMULATE>SETVAL|normal productivity[A]=0.08333
SIMULATE>SETVAL|normal productivity[B]=0.08333
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SIMULATE>SETVAL|normal productivity[D]=0.08333
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SIMULATE>SETVAL|normal productivity[G]=0.08333
SIMULATE>SETVAL|normal productivity[H]=0.08333
SIMULATE>SETVAL|normal productivity[I]=0.08333
SIMULATE>SETVAL|normal productivity[J]=0.08333

```
SIMULATE>SETVAL|maximum time to discover rework=18
SIMULATE>SETVAL|technology maturity factor[A]=1
SIMULATE>SETVAL|technology maturity factor[B]=.9
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SIMULATE>SETVAL|technology maturity factor[G]=1
SIMULATE>SETVAL|technology maturity factor[H]=1
SIMULATE>SETVAL|technology maturity factor[I]=1
SIMULATE>SETVAL|technology maturity factor[J]=1
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SIMULATE>SETVAL|complexity factor[D]=1
SIMULATE>SETVAL|complexity factor[E]=1
SIMULATE>SETVAL|complexity factor[F]=1
SIMULATE>SETVAL|complexity factor[G]=1
SIMULATE>SETVAL|complexity factor[H]=1
SIMULATE>SETVAL|complexity factor[I]=1
SIMULATE>SETVAL|complexity factor[J]=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on quality=1
SIMULATE>SETVAL|sensitivity for effect of schedule pressure on productivity=1
SIMULATE>RUNNAME|case 6a (TM,C=.9,AS=120)
MENU>RUN|O

SIMULATE>SETVAL|initial staff=120
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SIMULATE>SETVAL|initial work to do[B]=288
SIMULATE>SETVAL|initial work to do[C]=288
SIMULATE>SETVAL|initial work to do[D]=288
SIMULATE>SETVAL|initial work to do[E]=288
SIMULATE>SETVAL|initial work to do[F]=288
SIMULATE>SETVAL|initial work to do[G]=288
SIMULATE>SETVAL|initial work to do[H]=288
SIMULATE>SETVAL|initial work to do[I]=288
SIMULATE>SETVAL|initial work to do[J]=288
SIMULATE>SETVAL|estimated rework[A]=32
SIMULATE>SETVAL|estimated rework[B]=32
SIMULATE>SETVAL|estimated rework[C]=32
SIMULATE>SETVAL|estimated rework[D]=32
SIMULATE>SETVAL|estimated rework[E]=32
SIMULATE>SETVAL|estimated rework[F]=32
SIMULATE>SETVAL|estimated rework[G]=32
SIMULATE>SETVAL|estimated rework[H]=32
SIMULATE>SETVAL|estimated rework[I]=32
SIMULATE>SETVAL|estimated rework[J]=32
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SIMULATE>SETVAL|initial planned duration[B]=48
SIMULATE>SETVAL|initial planned duration[C]=48
SIMULATE>SETVAL|initial planned duration[D]=48
SIMULATE>SETVAL|initial planned duration[E]=48
SIMULATE>SETVAL|initial planned duration[F]=48
SIMULATE>SETVAL|initial planned duration[G]=48
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MENU>RUN|O

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MENU>RUN|O
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Appendix B

Single Project System Dynamics Model

Text File – Single Project Model.mdl

```
********************************************************
	.Single Project Model.mdl	A. McQuarrie
********************************************************~
		Simulation Control Parameters
	|

Total Cost Estimate=
	Rework Cost Estimate+Initial Cost Estimate
	~	Month*Person
	~		|

ACWP=
	Cumulative Effort Expended
	~	Person*Month
	~	Represents the actual cost for work performed. The ACWP is the actual \
		effort expended to complete the work believed to be done. ACWP is a \
		fundamental measure used in EVM (earned value management)
	|

Anticipated Schedule Overrun=
	((Perceived Real Completion Date-Scheduled Completion Date)/Scheduled Completion
Date\
		)*Project Finished
	~	Dimensionless
	~	The fraction by which the current estimate of completion date exceeds the \
		scheduled completion date.
	|

Average Productivity=
	IF THEN ELSE (Cumulative Effort Expended>0, Work Believed to Be Done/Cumulative
Effort Expended\
		,Productivity)
	~	Task/(Month*Person)
	~	Average productivity to date on the project simply equals work believed to \
		be done divided by cumulative effort (person-months) spent to date. Note \
		that this measure equates to productivity as defined in the model, and is \
		not adjusted for quality.
	|

Average Work Quality=
	Max(1e-006,Work Done)/Max(1e-006,Work Believed to Be Done)
	~	Fraction
	~	The average quality of all the "upstream" work done to date. This equals \
		work done (correctly) divided by total work done (which includes \
		undiscovered rework).
	|
```

BCWP=
(Initial Cost Estimate+Rework Cost Estimate)*Fraction Perceived to be Complete
~ Month*Person
~ Represents the budgeted cost for work performed. The BCWP is the \
planned/budgeted effort required to complete the fraction of work \
perceived to be complete. BCWP is a fundamental measure used in EVM \
(earned value management)
|

BCWS=
MIN(Time*(Rework Cost Estimate+Initial Cost Estimate)/Scheduled Completion Date, (Rework Cost Estimate\
+Initial Cost Estimate))
~ Month*Person
~ Represents the budgeted cost for work scheduled. The BCWS is the planned \
effort required to complete the work planned to be done. BCWS is a \
fundamental measure used in EVM (earned value management)
|

Budgeted Cost to Complete=
(Initial Cost Estimate+Rework Cost Estimate)*(1-Fraction Perceived to be Complete)
~ Month*Person
~ The budget estimate used in the model takes initial work to do, adds the \
estimated amount of rework expected on the project, and divides this by \
normal productivity to determine person-months required to execute the \
project. As fraction perceived complete increases, the "budget-based" \
amount of work remaining decreases.
|

Change in Schedule=
Max(0,Schedule Slip)/Time to Slip Schedule
~ Months/Month
~ |

Changes=
Work Done*(STEP(Fraction Changed/TIME STEP, Time of Change)-STEP(Fraction Changed/TIME STEP\
, Time of Change+TIME STEP))
~ Tasks/Month
~ |

Completion Off Switch=
IF THEN ELSE(Project Completion Date>1, 0, 1)
~ Dimensionless
~ |

Completion On Switch=
1-Project Finished
~ Dimensionless
~ |

Complexity Factor=
1
~ Dimensionless
~ The complexity factor is used to capture the quality effects attributed to \

the complexity of a project. For example, a project with many associate \
contractors or external interfaces can introduce added complexity which \
can result in rework due to misunderstood requirements, interface changes, \
etc. The rework or quality level of complex projects is typically higher \
than on projects with lower complexity.

|

Cost Overrun=

Cumulative Effort Expended-Total Cost Estimate

~ Month*Person

~ |

CPI=

IF THEN ELSE (Time>0, Project Finished*((BCWP+1e-005)/(ACWP+1e-005)), 1)

~ Fraction

~ CPI is the cost performance index. It is the ratio of BCWP to ACWP. A \
value greater than 1 indicates favorable cost performance (below plan) and \
a value less than 1 indicates unfavorable cost performance (ahead of plan)

|

Cumulative Effort Expended= INTEG (

Effort Expended,

0)

~ Person*Month

~ |

Cumulative Work Done= INTEG (

Rate of Doing Work,

0)

~ Tasks

~ Keeps track of how many total tasks have been done or redone on the \
project. Includes original work and rework.

|

Development Process Factor=

1

~ Dimensionless

~ Development Process Factor is used to scale the normal quality level. A \
high value reflects a mature and rigorous product development process \
where as a low value is reflective of an organization whose process is \
less mature and/or has been highly tailored (relaxed) to meet aggressive \
schedule demands.

|

Effect of Experience on Productivity=

IF THEN ELSE(Staff Level > 0, (General Staff*Relative Productivity of General Staff+\
Experienced Staff)/Staff Level

,1)

~ Dimensionless

~ New staff are assumed to be less productive than experienced staff. The \
effect simply weights the relative productivities of new and experienced \
staff by their proportion of the workforce.

|

Effect of Experience on Quality=
IF THEN ELSE(Staff Level > 0, (General Staff*Relative Quality of General Staff+Experienced Staff\
)/Staff Level,1)
~ Dimensionless
~ New staff are assumed to make more mistakes than experienced staff. The \
effect simply weights the relative quality of new and experienced staff by \
their proportion of the workforce.
|

Effect of Prior Work Quality on Quality=
Sensitivity for Effect of Quality on Quality*Table for Effect of Prior Work Quality on Quality\
(Average Work Quality)+(1-Sensitivity for Effect of Quality on Quality
)
~ Dimensionless
~ This effect represents the fact that undiscovered errors in upstream work \
products tend to cause errors in current work. The effect is specified in \
the table relationship driven by average work quality to date, and can be \
reduced or increased by the sensitivity multiple.
|

Effect of Requirements Uncertainty=
(Maximum Effect of Uncertain Customer Requirements+(1-Maximum Effect of Uncertain Customer Requirements\
)*Elimination of Uncertainty Based on Progress)* Switch for Effect of Uncertain Customer Requirements
+(1-Switch for Effect of Uncertain Customer Requirements)
~ Dimensionless
~ |

Effect of Schedule Pressure on Productivity=
Table for Effect of Schedule Pressure on PDY(Anticipated Schedule Overrun)*Sensitivity for Effect of Schedule Pressure on Productivity\
+(1-Sensitivity for Effect of Schedule Pressure on Productivity)
~ Dimensionless
~ Schedule pressure, based on the fraction by which the current estimate of \
completion date exceeds the original completion date, causes productivity \
to increase. That is, people are assumed to work faster, and perhaps \
longer hours as overtime is not included in this model, the greater the \
anticipated schedule overrun.
|

Effect of Schedule Pressure on Quality=
Sensitivity for Effect of Schedule Pressure on Quality*Table for Effect of Schedule Pressure on Quality\
(Anticipated Schedule Overrun)+(1-Sensitivity for Effect of Schedule Pressure on Quality\
)
~ Dimensionless
~ Schedule pressure, based on the fraction by which the current estimate of \
completion date exceeds the original completion date, causes quality to \
decrease. That is, while people are assumed to work faster, and perhaps \
longer hours as overtime is not included in this model, the greater the \
anticipated schedule overrun (see effect on productivity), they also make \
more mistakes in a "haste makes waste" effect. Also, overtime fatigue may \

cause additional errors.

|

Effect of Work Progress=
Table for Effect of Work Progress(Fraction Really Complete)
~ Dimensionless
~ Drives the time to discover rework from its maximum value to the minimum \
value as fraction really complete increases from 0 to 1.

|

Effort Expended=
Staff Level*Project Finished
~ People
~ |

Elimination of Uncertainty Based on Progress=
Table for Effect of Uncertain Customer Requirements(Fraction Perceived to be Complete\
)
~ Dimensionless
~ This parameter addresses the elimination of requirements uncertainty based \
on work believed to be complete. As more work is accomplished, \
requirements are confirmed through completion of requirements documents \
and reviews/acceptance by the customer, users, associate contractors, and \
subcontractors

|

Estimated Cost to Complete=
(Budgeted Cost to Complete*(1-"Weight on Progress-Based Estimates")+(Estimated Cost to Complete Based on Progress\
)*"Weight on Progress-Based Estimates")*Project Finished
~ Month*Person
~ Estimated cost to complete, in person-months, depends on the budgeted cost \
to complete and the estimated cost to complete based on progress. Early \
in the project before management can perceive actual productivity and \
quality, the tendency is to believe the budget. As progress is made, the \
weight on the progress-based estimate increases until that estimate \
replaces the budget cost estimate.

|

Estimated Cost to Complete Based on Progress=
Work to Do/Average Productivity
~ Month*Person
~ Estimated cost to finish the project, in person-months, is found by \
dividing work to do by average productivity. Note that this cost estimate \
does not adjust for any estimates of undiscovered rework, or for any \
trends in productivity or quality problems.

|

Estimated Rework=
32
~ Tasks
~ This value represents the estimated rework required on the project \
measured in tasks. In this case, the estimated rework is 10% of the tasks \
planned.

|

Excess Staff=
Max(0,Staff Level-Staff Level Required)
~ People
~ When staff level required is less than staff level, there are excess staff \
and therefore staff are laid off or transferred.
|

Experienced Staff= INTEG (
Staff Gaining Experience-Staff Leaving,
Initial Experienced Staff)
~ People
~ |

Extra Staff Needed=
Max(0,MIN(Maximum Staff Level,Staff Level Required)-Staff Level)
~ People
~ When staff required is larger than current staff level, extra staff are \
needed and may be hired (if willingness to hire is non-zero). A maximum \
staff level can be imposed by management.
|

Feasible Work Rate=
MIN(Maximum Work Rate,Potential Work Rate)
~ Tasks/Month
~ |

Fraction Changed=
0
~ Fraction
~ Used to represent a percent of rework required based on an internally or \
externally driven requirements change.
|

Fraction Complete to Finish=
0.99
~ Fraction
~ |

Fraction Perceived to be Complete=
Work Believed to Be Done/Initial Work to Do
~ Fraction
~ The fraction of work management believes is done correctly. This fraction \
includes undiscovered rework as well as work actually done correctly.
|

Fraction Really Complete=
Work Done/Initial Work to Do
~ Fraction
~ The fraction of work that is really complete in contrast to the fraction \
believed to be complete. The fraction really complete only includes work \
done, and not undiscovered rework.
|

Hiring Delay=
2
~ Months

~ Reflects the average time required to perceive the need for new staff and \
obtain them internally, or from outside the organization. This is longer \
than the transfer/firing delay, because locating people outside can be \
time consuming, and internal transfer may be slow because of needs on \
other projects.

|

Imputed Cost of Schedule Overrun=
Schedule Overrun*Imputed Cost Per Month of Overrun
~ Month*Person
~ |

Imputed Cost Per Month of Overrun=
0
~ Month*Person/Month
~ |

Indicated Completion Date Based on Progress=
Time+(Estimated Cost to Complete/Max(0.0001,Staff Level))
~ Month
~ Indicated completion date takes the current project time and adds to that \
the time required to finish the estimated work remaining assuming no \
change in staff (i.e., estimated cost to complete divided by current \
staff).

|

Initial Cost Estimate=
Initial Work to Do/Normal Productivity
~ Person*Month
~ |

Initial Experienced Staff=
80
~ People
~ |

Initial General Staff=
0
~ People
~ |

Initial Scheduled Completion=
48
~ Month
~ |

Initial Work to Do=
288
~ Tasks
~ The initial scope of the project.

|

Maximum Effect of Uncertain Customer Requirements=
0.85
~ Dimensionless
~ |

Maximum Staff Level=
160
~ People
~ Imposes an upper constraint on staff allowed on the project.
|

Maximum Time to Discover Rework=
18
~ Months
~ The time to discover rework early in the project when strictly design \
tasks are being done.
|

Maximum Work Rate=
Work to Do/Minimum Time to Finish a Task
~ Tasks/Month
~ |

Minimum Time to Finish Work=
1
~ Month
~ For planning staffing, the minimum time over which management desires to \
complete the remaining tasks. Note that this is larger than the minimum \
time required to finish any one task.
|

Minimum Time to Discover Rework=
0.25
~ Months
~ The time to discover rework late in the project when building and testing \
tasks are being done.
|

Minimum Time to Finish a Task=
0.125
~ Months
~ The average minimum time it takes to execute a task.
|

General Staff= INTEG (
+Staff Hired-Staff Gaining Experience-General Staff Leaving,
Initial General Staff)
~ People
~ |

General Staff Leaving=
(MIN(Excess Staff,General Staff)/"Transfer/Layoff Delay")*"Weight on Progress-Based Estimates"\
*"Willingness to Transfer/Layoff"
~ People/Month
~ If there are excess staff, new staff are transferred or fired up to the \
number of new staff. Early in the project, the weight on progress-based \
estimates prevents layoffs that might occur because early progress \
measures are optimistic and indicate a surplus of staff.
|

Normal Productivity=
0.08333
~ Task/(Month*Person)
~ The represents the normal productivity level expected on average
|

Normal Quality=
0.9
~ Fraction
~ |

Perceived Real Completion Date=
SMOOTHI(Indicated Completion Date Based on Progress,Time to Perceive Real Schedule,Scheduled Completion Date\
)
~ Month
~ Perceived completion date lags indicated completion date. This lag \
reflects delays in management's perception of the real status of the \
project, or reluctance to act on that status.
|

Percent Cost Overrun=
100*(Cost Overrun)/Total Cost Estimate
~ Dimensionless
~ |

Percent Schedule Overrun=
100*(Schedule Overrun)/Initial Scheduled Completion
~ Dimensionless
~ |

Potential Work Rate=
Staff Level*Productivity*Project Finished
~ Tasks/Month
~ The rate at which tasks could be accomplished if there is enough work to \
be done.
|

Productivity=
Normal Productivity*Effect of Schedule Pressure on Productivity*Effect of Experience on Productivity\
*(Effect of Requirements Uncertainty
Relative Effect of Uncertainty on P+(1-Relative Effect of Uncertainty on P))"Program Red?"
~ Task / (Person * Month)
~ Productivity represents tasks accomplished per person-month of effort, \
whether done right or wrong. Normal productivity is the output that would \
result if the impacts of all simulated effects on productivity are 1.0; \
therefore, normal productivity represents the effects of all non-modeled \
factors on productivity.
|

"Program Red?"=
IF THEN ELSE(Scheduled Completion Date=48:AND:CPI<0.9:OR:SPI<0.9, 0.9*Project Finished\
, 1*Project Finished)

~

~ A program or project is considered "Red" if the CPI or SPI is less than \
0.9. This parameter used to scale productivity and quality as a result of \
the program going "Red". Going "Red" creates additional burden and \
pressure on the staff as a result of unplanned reporting activities \
(reviews, meetings, etc) to the customer or senior management. \
Productivity will be reduced since staff will be diverted to unplanned \
activities. Quality will be reduced due to the additional pressure on the \
staff and a tendency to skip process steps and accelerate tasks. Note, if \
the schedule is allowed to slip and the scheduled finish date changes from \
48 months then it is assumed that the project is restructured and the \
project will no longer be "Red".

|

Project Completion Date= INTEG (
Recognition of Completion,
0)
~ Month
~ |

Project Completion Switch=
Completion On Switch*Completion Off Switch
~ Dimensionless
~ |

Project Finished=
IF THEN ELSE(Work Done>Fraction Complete to Finish*Initial Work to Do,0,1)
~ Dimensionless
~ The project is defined to be finished when 99% of the work is done. The \
project finished switch shuts off the application and accounting of labor \
to the project.

|

Quality=
Normal Quality*Effect of Prior Work Quality on Quality*Effect of Schedule Pressure on Quality\
*Effect of Experience on Quality
Effect of Requirements Uncertainty"Program Red?"*Complexity Factor*Technology Maturity Factor\
*Development Process Factor
~ Fraction
~ This represents the normal quality level expected on average

|

Rate of Doing Work=
Rework Generation+Work Accomplishment
~ Tasks/Month
~ |

Recognition of Completion=
Project Completion Switch*(Time-Project Completion Date)/TIME STEP
~ Month/Month
~ |

Relative Effect of Uncertainty on P=
0.5

~ Fraction
~ Represents the impact of uncertainty in requirements on productivity. \
Note, as uncertainty increases productivity will tend to decrease
|

Relative Productivity of General Staff=
0.75
~ Fraction
~ |

Relative Quality of General Staff=
0.5
~ Fraction
~ |

Rework Cost Estimate=
Estimated Rework/Normal Productivity
~ Person*Month
~ Rework cost estimate (RCE) represents the budget allocation established \
for "known-unknowns". That is, it is known that there will be some rework \
required based on past program performance, however, it is unknown exactly \
which tasks will require rework. RCE is estimated to be 10% of the initial \
work to do.
|

Rework Discovery=
(Undiscovered Rework/Time to Discover Rework)*Project Finished
~ Task / Month
~ The rate of discovering errors in prior work products.
|

Rework Generation=
(1-Quality)*Feasible Work Rate
~ Task / Month
~ Work being done incorrectly.
|

Schedule Overrun=
Max(0,Project Completion Date-Initial Scheduled Completion)
~ Months
~ |

Schedule Slip=
Willingness to Slip*Max(0,(Perceived Real Completion Date-Scheduled Completion
Date)\
)*Table for Schedule Slip
(Fraction Perceived to be Complete)
~ Months
~ |

Scheduled Completion Date= INTEG (
Change in Schedule,
Initial Scheduled Completion)
~ Month
~ |

Sensitivity for Effect of Quality on Quality=
0.5
~ Dimensionless
~ Increases or decreases the strength of the effect of prior quality on \
current quality specified in the graphical relationship.
|

Sensitivity for Effect of Schedule Pressure on Productivity=
1
~ Dimensionless
~ Increases or decreases the strength of the effect of schedule pressure on \
current productivity specified in the graphical relationship.
|

Sensitivity for Effect of Schedule Pressure on Quality=
1
~ Dimensionless
~ Increases or decreases the strength of the effect of schedule pressure on \
current quality specified in the graphical relationship.
|

SPI=
IF THEN ELSE (Time>0, ((BCWP+1e-009)/(BCWS+1e-009))*Project Finished, 1)
~ Fraction
~ SPI is the schedule performance index. It is the ratio of BCWP to BCWS. \
A value greater than 1 indicates performance ahead of schedule and a value \
less than 1 indicates performance behind schedule
|

Staff Gaining Experience=
General Staff/Time to Gain Experience
~ People/Month
~ |

Staff Hired=
IF THEN ELSE("Program Red?"=0.9, Willingness to Hire*Extra Staff Needed/Hiring Delay\
, 0)
~ People/Month
~ |

Staff Leaving=
(Max(0,(Excess Staff-General Staff))/"Transfer/Layoff Delay")*"Weight on Progress-Based Estimates"\
*"Willingness to Transfer/Layoff"
~ People/Month
~ Any excess staff above new staff is eliminated by transferring or firing \
experienced staff.
|

Staff Level=
(General Staff+Experienced Staff)
~ People
~ Total staff including new and experienced staff. Note, the initial staff \
level represents the average staff level required to complete all the \
planned tasks as well as the estimated rework for the scheduled completion \

date at a given quality and productivity level.

|

Staff Level Required=
Estimated Cost to Complete/Time Remaining
~ People
~ |

Switch for Effect of Uncertain Customer Requirements=
0
~ Dimensionless
~ Set to 1 to enable impact of uncertain requirements. Set to 0 for \
disabling impact of uncertain requirements
|

Table for Effect of Prior Work Quality on Quality(
[(0,0)-(1,1)],(0,0.05),(0.1,0.1),(0.2,0.2),(0.3,0.3),(0.4,0.4),(0.5,0.5),(0.6,0.6),(\
0.7,0.7),(0.8,0.8),(0.9,0.9),(1,1))
~ Dimensionless
~ |

Table for Effect of Schedule Pressure on PDY(
[(-0.2,0)-(1,2)],(-0.2,0.85),(-0.1,0.95),(0,1),(0.1,1.025),(0.2,1.075),(0.3,1.15),(0.4\
,1.25),(0.5,1.325),(0.6,1.375),(0.7,1.4))
~ Dimensionless
~ |

Table for Effect of Schedule Pressure on Quality(
[(0,0)-
(1,1)],(0,1),(0.103976,0.991228),(0.214067,0.951754),(0.30581,0.881579),(0.406728\
,0.811404),(0.5,0.758772),(0.599388,0.736842),(0.703364,0.732456))
~ Dimensionless
~ |

Table for Effect of Uncertain Customer Requirements(
[(0,0)-(1,1)],(0,0),(0.1,0),(0.2,0),(0.3,0),(0.4,0),(0.5,0),(0.6,0.1),(0.7,0.3),(0.8\
,0.6),(0.9,0.85),(1,1))
~ Dimensionless
~ |

Table for Effect of Work Progress(
[(0,0)-(1,1)],(0,1),(0.1,1),(0.214067,0.973684),(0.33945,0.916667),(0.422018,0.77193\

),(0.5,0.6),(0.6,0.364035),(0.678899,0.214912),(0.8,0.0877193),(0.896024,0.0394737)\
,(1,0))
~ Dimensionless
~ |

Table for Schedule Slip(
[(0,-0.006)-(1,1)],(0,0),(0.0030581,0),(0.293578,0),(0.3,1),(0.4,1),(0.5,1),(0.6,1),\
(0.7,1),(0.8,1),(0.9,1),(1,1))
~ Dimensionless
~ |

"Table for Weight on Progress-Based Estimates"(
[(0,0)-(1,1)],(0,0),(0.1,0),(0.2,0),(0.296636,0.00877193),(0.345566,0.0263158),(0.388379\

,0.0745614),(0.458716,0.241228),(0.574924,0.635965),(0.672783,0.864035),(0.730887,
0.942982\
),(0.8,1),(0.9,1),(1,1))
~ Fraction
~ |

Technology Maturity Factor=
1
~ Dimensionless
~ Technology maturity refers to the maturity and development organization \
experience with the technology applied to the project. The value defined \
here is used to offset the normal quality level.
|

Time of Change=
15
~ Month
~ Represents point in time where the changes are identified
|

Time Remaining=
Max(Minimum Time to Finish Work,Scheduled Completion Date-Time)
~ Month
~ The months remaining before the project reaches the scheduled completion \
date. Once that date is reached, the model assumes that management tries \
to finish the project in a minimum time.
|

Time to Discover Rework=
Maximum Time to Discover Rework*Effect of Work Progress+(1-Effect of Work
Progress)*\
Minimum Time to Discover Rework
~ Month
~ The average time between when an error is created and when it is \
discovered. This average is assumed to start at a maximum value early in \
the project, and then fall to a minimum value as the fraction of the \
project completed increases. Because this model represents the entire \
project, we assume that early activities create the design, which is then \
later coded and tested (if software) or built (if hardware). Therefore, \
errors are most readily discovered when the project is in the code/test or \
build phases.
|

Time to Gain Experience=
36
~ Months
~ |

Time to Perceive Real Schedule=
1+(1-Project Finished)*1e+006
~ Month
~ During the project, the effective time constant is 1 month; after project \
finishes, the time constant is set to a large number such that the \
equations recognize the project completion date has occurred.
|

Time to Slip Schedule=
1
~ Months
~ |

Total Project Cost=
Cumulative Effort Expended+Imputed Cost of Schedule Overrun
~ Month*Person
~ |

"Transfer/Layoff Delay"=
0.5
~ Months
~ It is assumed that only one month is required to lay off or transfer \
workers.
|

Undiscovered Rework= INTEG (
Rework Generation-Rework Discovery+Changes,
0)
~ Task
~ Work which contains errors and will need to be redone, but the need for \
which has not yet been recognized.
|

"Weight on Progress-Based Estimates"=
"Table for Weight on Progress-Based Estimates"(Fraction Perceived to be Complete)
~ Fraction
~ Management is assumed to switch from a budget-based estimate of effort \
remaining to the progress-based estimate as fraction perceived complete \
increases. The weight on progress-based estimates is also used to prevent \
layoffs early in the project, when failure to consider rework and \
productivity/quality problems might otherwise indicate an excess of staff.
|

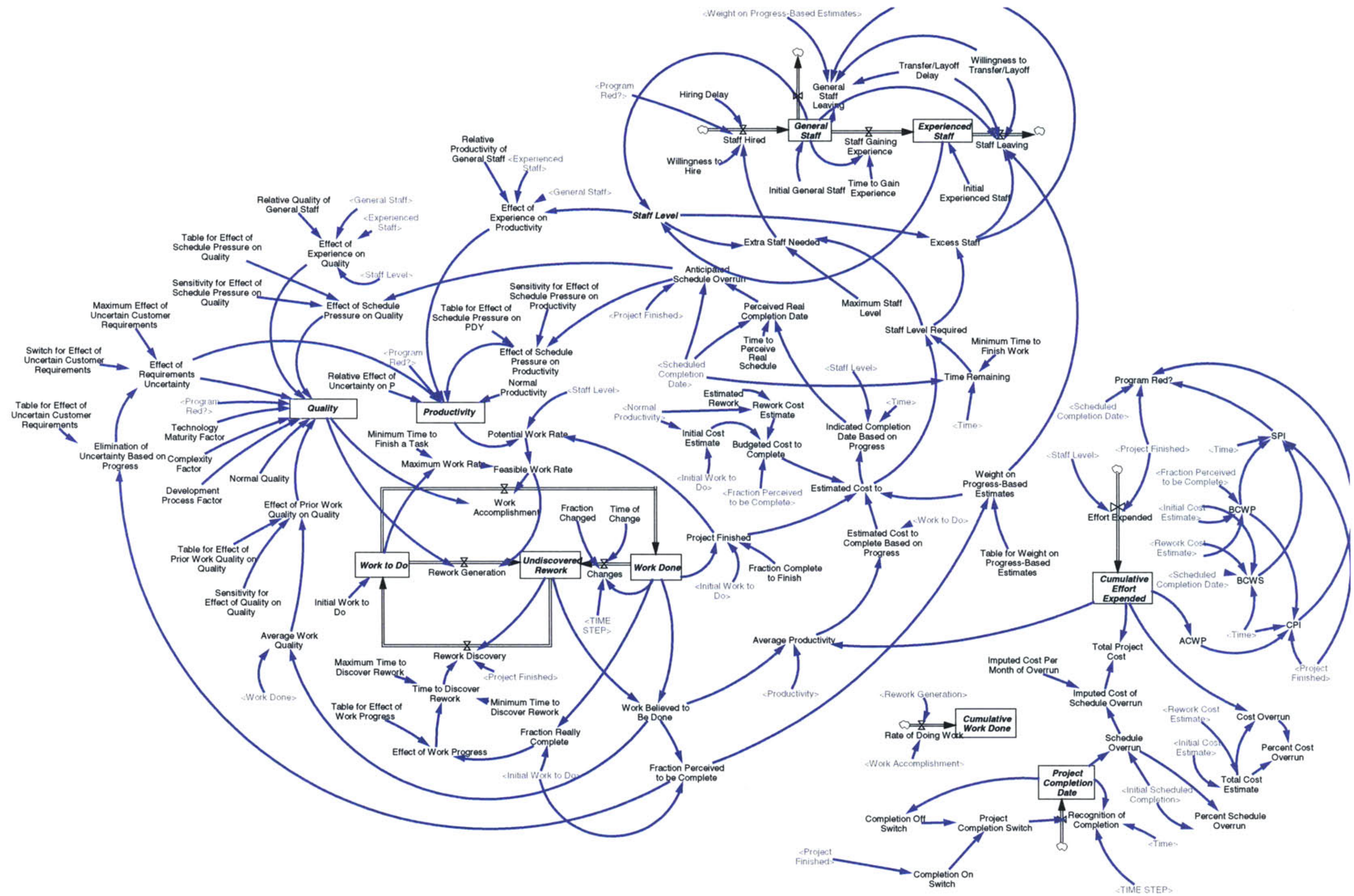
Willingness to Hire=
0
~ Dimensionless
~ A fraction between 0 and 1: 0 means no hiring, and 1 means hiring as \
indicated to get the work done in the time remaining. While willingness \
can be anywhere between 0 and 1.
|

Willingness to Slip=
0
~ Dimensionless
~ A fraction between 0 and 1: 0 means no schedule slip allowed, and 1 means \
slipping the schedule as required.
|

"Willingness to Transfer/Layoff"=
0
~ Dimensionless
~ |

```
Work Accomplishment=
        Quality*Feasible Work Rate
        ~       Task / Month
        ~       Work being done correctly.
        |

Work Believed to Be Done=
        Undiscovered Rework+Work Done
        ~       Tasks
        ~       Work believed by management to be done at any time includes work actually \
                done correctly plus undiscovered rework.
        |

Work Done= INTEG (
        Work Accomplishment-Changes,
                0)
        ~       Task
        ~       Work done correctly.
        |

Work to Do= INTEG (
        Rework Discovery-Rework Generation-Work Accomplishment,
                Initial Work to Do)
        ~       Task
        ~       Work to do on the project includes the initial scope, plus tasks which \
                include errors as these errors are discovered.
        |

********************************************************
        .Control
********************************************************~
                Simulation Control Parameters
        |

FINAL TIME  = 100
        ~       Month
        ~       The final time for the simulation.
        |

INITIAL TIME  = 0
        ~       Month
        ~       The initial time for the simulation.
        |

SAVEPER  =
      TIME STEP
        ~       Month
        ~       The frequency with which output is stored.
        |

TIME STEP  = 0.0625
        ~       Month
        ~       The time step for the simulation.
        |
```

Single Project Model Sketch – Workflows & Staffing



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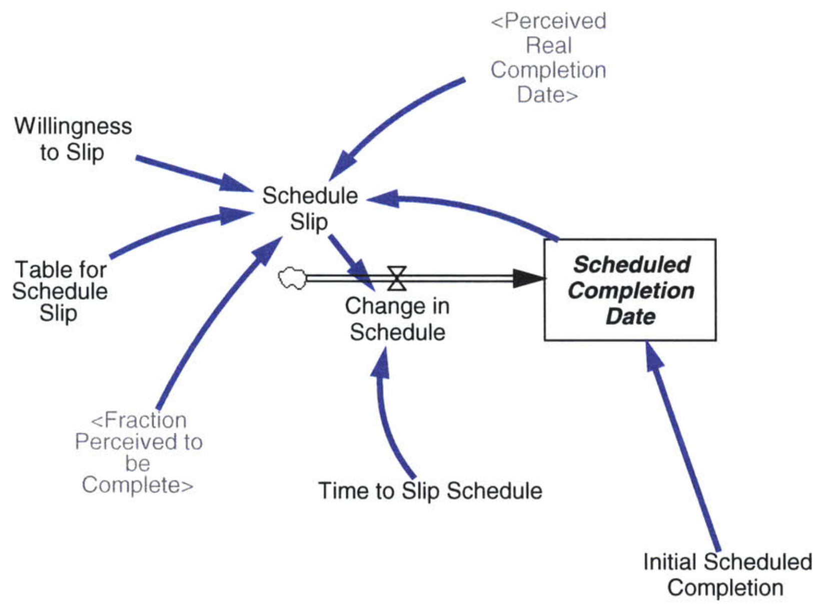
Single Project Model Sketch – Schedule



Command File – Single project.cmd

```
SIMULATE>SETVAL|initial general staff=0
SIMULATE>SETVAL|initial experienced staff=80
SIMULATE>SETVAL|willingness to hire=0
SIMULATE>SETVAL|willingness to transfer/layoff=0
SIMULATE>SETVAL|technology maturity factor=1
SIMULATE>SETVAL|complexity factor=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0.5
SIMULATE>SETVAL|willingness to slip=0
SIMULATE>RUNNAME|100
MENU>RUN|O

SIMULATE>SETVAL|initial general staff=20
SIMULATE>SETVAL|initial experienced staff=60
SIMULATE>SETVAL|willingness to hire=0
SIMULATE>SETVAL|willingness to transfer/layoff=0
SIMULATE>SETVAL|technology maturity factor=1
SIMULATE>SETVAL|complexity factor=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0.5
SIMULATE>SETVAL|willingness to slip=0
SIMULATE>RUNNAME|75_25
MENU>RUN|O

SIMULATE>SETVAL|initial general staff=40
SIMULATE>SETVAL|initial experienced staff=40
SIMULATE>SETVAL|willingness to hire=0
SIMULATE>SETVAL|willingness to transfer/layoff=0
SIMULATE>SETVAL|technology maturity factor=1
SIMULATE>SETVAL|complexity factor=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0.5
SIMULATE>SETVAL|willingness to slip=0
SIMULATE>RUNNAME|50_50
MENU>RUN|O

SIMULATE>SETVAL|initial general staff=60
SIMULATE>SETVAL|initial experienced staff=20
SIMULATE>SETVAL|willingness to hire=0
SIMULATE>SETVAL|willingness to transfer/layoff=0
SIMULATE>SETVAL|technology maturity factor=1
SIMULATE>SETVAL|complexity factor=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0.5
SIMULATE>SETVAL|willingness to slip=0
SIMULATE>RUNNAME|25_75
MENU>RUN|O

SIMULATE>SETVAL|initial general staff=0
SIMULATE>SETVAL|initial experienced staff=70
SIMULATE>SETVAL|Relative Quality of General Staff=.5
SIMULATE>SETVAL|Relative Productivity of General Staff=.5
SIMULATE>SETVAL|willingness to hire=1
```

```
SIMULATE>SETVAL|"willingness to transfer/layoff"=1
SIMULATE>SETVAL|technology maturity factor=.9
SIMULATE>SETVAL|complexity factor=.9
SIMULATE>SETVAL|development process factor=.9
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0.5
SIMULATE>SETVAL|willingness to slip=0
SIMULATE>RUNNAME|hire genstaff
MENU>RUN|O

SIMULATE>SETVAL|initial general staff=0
SIMULATE>SETVAL|initial experienced staff=70
SIMULATE>SETVAL|Relative Quality of General Staff=1
SIMULATE>SETVAL|Relative Productivity of General Staff=1
SIMULATE>SETVAL|willingness to hire=1
SIMULATE>SETVAL|"willingness to transfer/layoff"=1
SIMULATE>SETVAL|technology maturity factor=.9
SIMULATE>SETVAL|complexity factor=.9
SIMULATE>SETVAL|development process factor=.9
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0.5
SIMULATE>SETVAL|willingness to slip=0
SIMULATE>RUNNAME|hire expstaff
MENU>RUN|O

SIMULATE>SETVAL|initial general staff=0
SIMULATE>SETVAL|initial experienced staff=80
SIMULATE>SETVAL|Relative Quality of General Staff=1
SIMULATE>SETVAL|Relative Productivity of General Staff=1
SIMULATE>SETVAL|willingness to hire=0
SIMULATE>SETVAL|"willingness to transfer/layoff"=1
SIMULATE>SETVAL|technology maturity factor=1
SIMULATE>SETVAL|complexity factor=1
SIMULATE>SETVAL|development process factor=1
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0.5
SIMULATE>SETVAL|willingness to slip=0
SIMULATE>RUNNAME|plan
MENU>RUN|O

SIMULATE>SETVAL|initial general staff=0
SIMULATE>SETVAL|initial experienced staff=80
SIMULATE>SETVAL|Relative Quality of General Staff=1
SIMULATE>SETVAL|Relative Productivity of General Staff=1
SIMULATE>SETVAL|willingness to hire=0
SIMULATE>SETVAL|"willingness to transfer/layoff"=1
SIMULATE>SETVAL|technology maturity factor=.9
SIMULATE>SETVAL|complexity factor=.9
SIMULATE>SETVAL|development process factor=.9
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0.5
SIMULATE>SETVAL|willingness to slip=0
SIMULATE>RUNNAME|const staff
MENU>RUN|O

SIMULATE>SETVAL|initial general staff=0
SIMULATE>SETVAL|initial experienced staff=80
SIMULATE>SETVAL|Relative Quality of General Staff=1
SIMULATE>SETVAL|Relative Productivity of General Staff=1
SIMULATE>SETVAL|willingness to hire=0
```

```
SIMULATE>SETVAL|"willingness to transfer/layoff"=1
SIMULATE>SETVAL|technology maturity factor=.9
SIMULATE>SETVAL|complexity factor=.9
SIMULATE>SETVAL|development process factor=.9
SIMULATE>SETVAL|sensitivity for effect of quality on quality=0.5
SIMULATE>SETVAL|willingness to slip=1
SIMULATE>RUNNAME|const staff_slip
MENU>RUN|O
```

6572-105